T-71-02002

LIGHTWEIGHT EVACUATED MULTILAYER INSULATION SYSTEMS FOR THE SPACE SHUTTLE VEHICLE

NAS 3-14369

Quarterly Technical Progress Report No. 2

Covering Period July 1, 1971 through September 30, 1971

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October 1, 1971

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INTRODUCTION

This program consists of a nine month design, analytical and experimental evaluation of lightweight evacuated multilayer insulation (MLI) systems for the on-orbit propellant (LH_2 and LO_2) tanks of the Space Shuttle orbiter. The objective is to develop an evacuated insulation system which will combine maximum performance with minimum weight, be highly reliable, require minimum maintenance, and provide a constant level of performance for at least 100 flights.

The study will be performed in three major tasks consisting of design concepts evaluation, vacuum shell structural tests and vacuum acquisition tests, and data evaluation and reports.

The first three months will be devoted to design and trade studies of the self-supporting and the semi-rigid vacuum shell insulation systems. These studies are intended to investigate tank assembly configurations, but with the major emphasis on critical vacuum shell details; provide analytical data for evaluation and selection of shell materials and configurations; and to provide data on thermal performance, vacuum acquisition, propellant leakage isolation, inspection and repairs, shell handling procedures and vacuum tight welding. The MLI systems studied will be evaluated and ranked during the remaining two months of the TASK I study. Recommendations will be made to NASA/LeRC on the basis of this evaluation.

The TASK II experimental investigations are programmed to provide supporting data for the design and trade studies, and to determine adequacy of selected designs and test procedures. Material outgassing tests on sandwich shell materials, vacuum acquisition tests and external pressure tests on two 45" diameter hemispherical sandwich shells, and a non-destructive proof test on an 8' diameter ellipsoidal sandwich shell will be performed.

TASK III will evaluate the data from the design, trade and experimental studies. The remaining uncertainties or other technical deficiencies which require resolution before application of the evacuated MLI system to Space Shuttle will be identified to NASA/LeRC.

PROGRESS

1.0 TASK I - Design Concepts Evaluation

1.1 Design and Trade Studies

A. Design Studies (Supporting Investigations)

A.1 Thermal Analysis

A preliminary assessment of MLI systems was made to identify those best suited for use in the vacuum annulus. Several factors were considered. These were; (1) MLI weight, (2) outgassing characteristics, (3) thermal performance prediction accuracy, and (4) installation complexity.

In this study it was assumed that sufficient layers of aluminized kapton were employed on the outside of the blanket to reduce working temperatures to the point where aluminized mylar, and silk, dacron or nylon nets could be used.

The multilayer concepts evaluated were (1) NRC-2 (using 15 gage mylar), (2) 15 gage aluminized mylar with nylon net spacers, (3) 15 gage aluminized mylar with two silk net spacers per layer, and (4) 15 gage aluminized mylar with tissu-glas spacers. Typical support and fluid line configurations were assumed and the heat flow for these subtracted from the total allowance (0.1 to 0.7 Btu/Hr-Ft^2). Eight fiberglass tank supports, approximately 10" long, were selected. The fill and vent lines were 2.5" and 3.0" diameter with 0.035" wall thickness and were routed 1/4 the distance around the hemispherical tank head before exiting the vacuum annulus.

MLI blanket thicknesses were derived using the insulation conductivity equation $k = k_r(T_1^2 + T_2^2)(T_1 + T_2) + k_c(T_1 + T_2)$. The k_c and k_r constants for several insulation concepts are defined in Table 1.

On a least-weight basis, NRC-2 is the best concept. The nearest competitor is aluminized mylar/nylon net which is about 17-1/2% heavier for equal conductance.

Table 1 : INSULATION CONDUCTIVITY EQUATIONS

$$k = k_r (T_1^2 + T_2^2)(T_1 + T_2) + k_c (T_1 + T_2), \text{ BTU/FT-HR-}^{\circ}\text{R}$$

where T_1 and T_2 are the boundary temperatures

$$k_r = \frac{\sigma}{12n\left(\frac{2}{\epsilon} - 1\right)}$$ (unless taken directly from reference 7) (Through layers only)

σ = Stefan-Boltzmann Constant
n = layers/inch
ε = .025

k_c = constant selected to fit test data

INSULATION	n	ρ, LB/FT^3		THROUGH LAYERS			ALONG LAYERS	
		.25 Mil*	.15 Mil*	k_r	k_c	Ref.	k_r	k_c
NRC-2	70	1.55	0.94	9.6×10^{-14}	0.89×10^{-8}	7	1.19×10^{-10}	8.4×10^{-6}
Aluminized mylar-nylon net	70	3.84	3.25	2.5×10^{-14}	0.53×10^{-8}	8	0.75×10^{-10}	16.8×10^{-6}
Aluminized mylar-2 silk net	23	1.18	0.98	7.8×10^{-14}	2.20×10^{-8}	6	0.66×10^{-10}	6.4×10^{-6}
Aluminized mylar-polyurethane foam	29.5 21.7	1.83 1.93	1.57 1.72	6.1×10^{-14} 8.3×10^{-14}	2.00×10^{-8} 5.80×10^{-8}	8 7	0.26×10^{-10}	8.3×10^{-6}
Aluminized mylar-tissuglas	82	2.82	2.11	3.7×10^{-14}	3.10×10^{-8}	7	0.26×10^{-10}	23.0×10^{-6}

* Mylar Thickness

For the near spherical LH_2 tank (L/D = 1.09), insulation weight using NRC-2 is roughly 110 lb., therefore a nineteen pound penalty for a system with better handling characteristics and resistance to compaction such as shields and net spacers is relatively small in terms of total tankage weight. For the same tank, the aluminized mylar-silk net combination was 24% heavier than NRC-2 and the aluminized mylar-tissuglas was 245% heavier.

Outgassing characteristics of multilayer materials have been determined in past IR&D investigations at Boeing. Thermogravimetric analyses have shown that room temperature weight loss of aluminized mylar is 0.072%, nylon net is 3.16%, dacron net is 0.132% and silk net is approximately 7.00%. Lower temperatures ($\approx -25^{\circ}F$) reduce the outgassing significantly.

In terms of minimum outgassing, the NRC-2 appears to be the best choice again. A near competitor would be aluminized mylar with dacron net spacers. This combination (assuming aluminized mylar/nylon net heat transfer characteristics) required 43 shields and 44 spacers to meet tank heat flow requirements, whereas the NRC-2 requires 126 shields. It is possible that the higher outgassing of the dacron net could be offset by the reduced number of shields, thus the two systems could be equally efficient.

The nylon and silk nets do not appear to be a good choice for this application because of their initial high moisture content and affinity for water vapor. It would be possible to achieve optimum performance with these materials through preconditioning, however, loss of vacuum during ground turnaround would necessitate repetition of the preconditioning procedure.

Boeing experience has shown that NRC-2 is difficult to apply to a specific layer density. Also the material shows little in the way of "recovery" when subjected to compression loading. In thicker blankets, such as the 1.8 inches required for one design case, gravity will influence the applied thickness in different locations on the tank. In the event that NRC-2 is chosen, the heat flow will be more difficult to predict accurately and the labor involved in application of the MLI will be greater than for other systems. On the other hand, a conservative design by means of increased multilayer thickness is possible without incurring large weight penalties.

Experience has shown that net spacers add resilience and strength to a MLI system. Application to a specific layer ratio is more easily accomplished, thus the accuracy of thermal performance predictions is better. If experimental data were available to show that aluminized mylar/dacron net MLI had the same apparent conductivity as aluminized mylar/nylon net, then that concept appears to be the best choice. However, without this data, NRC-2 is preferred primarily because of its low outgassing characteristics. There may be some difficulty with application and reuseability, but conservative blanket design should compensate for this.

A.2 Vacuum Acquisition Studies

Maximum thermal efficiency of the MLI system requires a vacuum level between 5×10^{-5} and 1×10^{-4} torr. A check was made to determine the number of days required to degrade a vacuum annulus from 1×10^{-5} to 1×10^{-4} torr for different leak rates. The tank configuration selected was the 15 ft. diameter LH_2 tank with a pressure vessel volume of 2000 cu. ft. and an insulation vacuum annulus thickness of 4.5 inches. The volume of the vacuum annulus was calculated as 8.572×10^6 cubic centimeters.

The number of days to degrade the vacuum annulus from 1×10^{-5} to 1×10^{-4} torr was calculated as follows:

For a leak rate of 1.0×10^{-6} std atm cc of air/sec, the number of days are:

$$\frac{10^{-4}\ (1 - 10^{-1}),\ \times 8.572 \times 10^{6}}{760 \times 10^{-6} \times 3600 \times 24} = 11.8 \text{ Days}$$

The results are summarized as follows:

Leak Rate (Std cc of air/sec)	Number of Days to Degrade Vacuum Annulus from 1×10^{-5} to 1×10^{-4} Torr
1×10^{-6}	11.8
1×10^{-5}	1.18
1×10^{-4}	.118

This analysis does not account for the vacuum pumping system created at the pressure vessel surface when it is cooled to $-423^{\circ}F$ by the LH_2. Gases in the vacuum annulus, except for helium, neon and hydrogen, will be cryopumped to pressure vessel surface. Thermal performance of the MLI will undoubtedly be degraded from the condensables collecting on the surfaces of those layers adjacent to the pressure vessel. Also, outgassing from materials in the vacuum annulus was not considered in the analysis.

Results from this study provide a basis for establishing target leak rates during vacuum acquisition testing of the two 45" diameter hemispherical heads.

A.3 Propellant Leakage Isolation

Two tank penetration arrangements are described in detail in Section 1.1.B.1. These are designed to minimize exposure of the insulation annulus to propellant leakage. Loss of vacuum and/or change in emissivity of the reflective shields resulting from leakage will degrade the thermal performance of the M.L.I. system.

Briefly, one penetration arrangement seals off the insulation annulus from the possible leak source. The other relies on the integrity of mechanical joints with seals, as well as vacuum acquisition procedures to maintain the required vacuum level in the insulation annulus.

These penetration arrangements will be evaluated on the basis of heat leak, weight, fabrication complexity and system reliability.

B. Design Studies (Design Preparation)

B.1 Tank Configuration Study

Design studies on the LH_2 tanks are in progress. Figure 1 shows the 15 ft. diameter near spherical tank located in the orbiter, aft of the main propulsion tanks. Attachment to the primary structure is from the vacuum jacket girth ring. This ring is shown in the figure aligned horizontally in the orbiter. Alternatively, it can be aligned vertically. Limited definition of the primary structure at this time prevents a meaningful detail study of the tank to vehicle support structure. It appears, however, that attachment can be made to the fuselage side frames and/or the fin support structure.

Penetrations

Plumbing and manhole penetration arrangements are shown in Figure 2 . The girth ring for the LH_2 tank described is aligned horizontally in the vehicle. The penetrations are placed at the apex of the tank domes for manufacturing simplicity. Alternate locations on the dome are possible, providing the clearance hole in the vacuum jacket is sufficient for installation. The vent line is routed inside the pressure vessel. The inlet is located for venting when the vehicle is in the launch position. The penetration arrangements shown are also applicable to other LH_2 tank orientations and L/D ratios.

The vent line arrangement shown in Section A-A uses the high reliability welded and brazed joints to prevent propellant leakage from contaminating the insulation annulus. The vent relief valve is mounted externally, isolating the insulation annulus from possible seal leakage. Low valve temperatures, maintained by adequate insulation on the valve and line, will prevent high heat transfer through the wet line connecting the valve and pressure vessel.

Similarly, the arrangement in Section B-B showing the manhole cover with integral fill and discharge line will also require external insulation. Both of these arrangements provide positive isolation of the vacuum annulus from inadvertent leakage around the manhole cover and the plumbing penetrations.

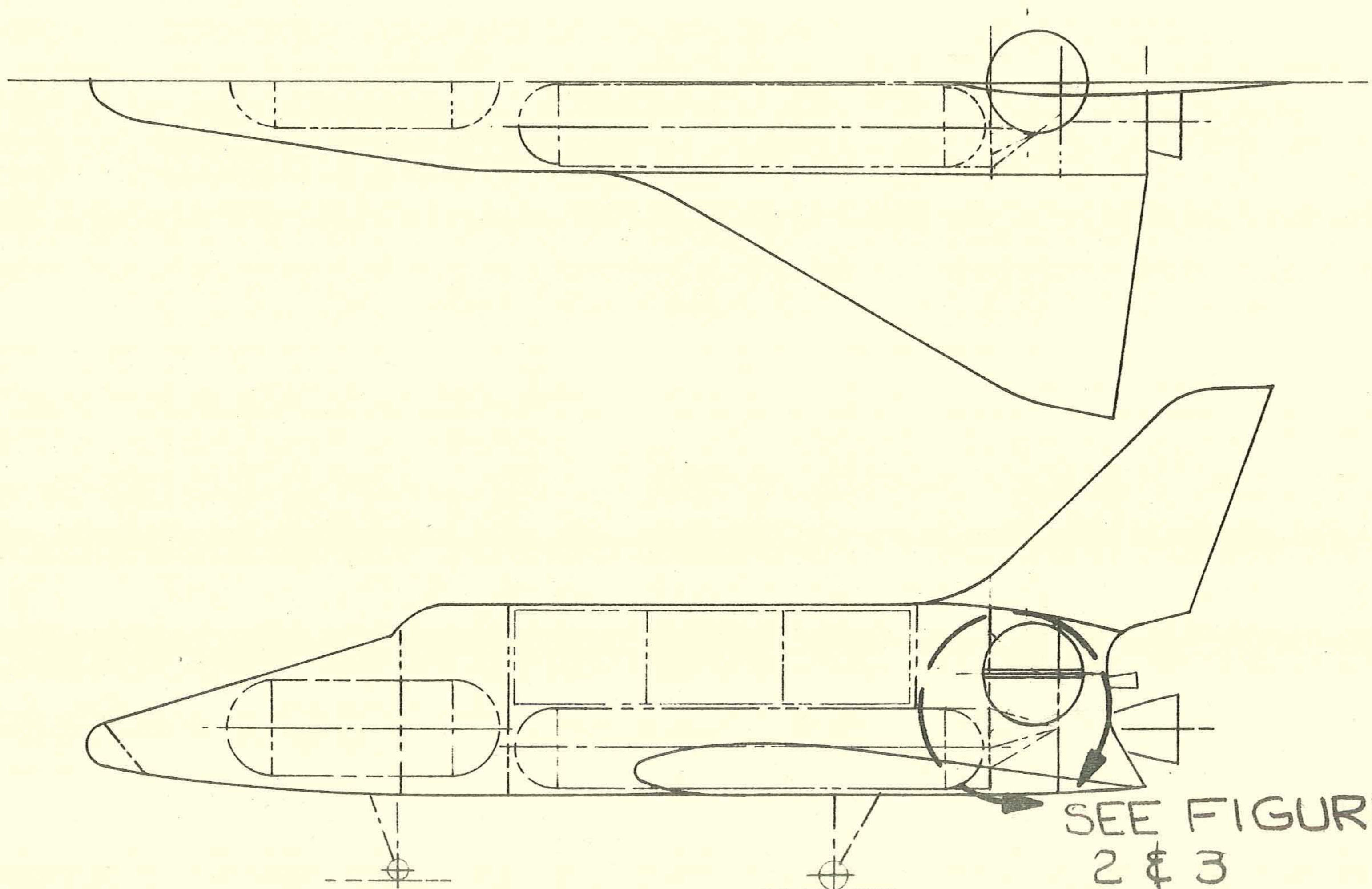

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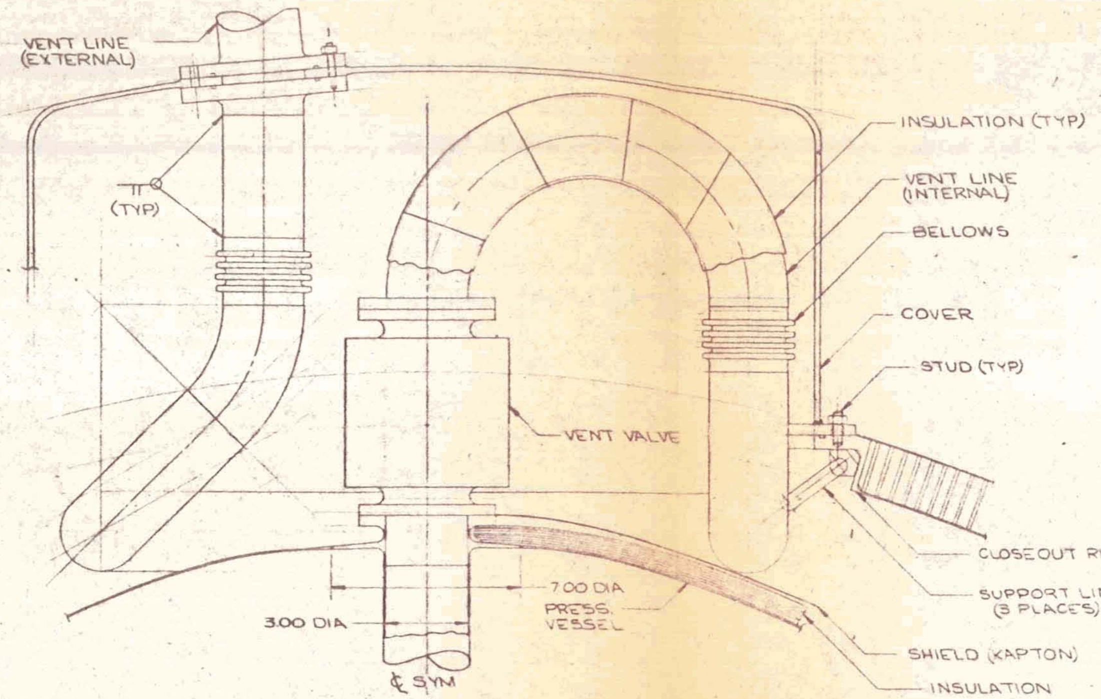
FIGURE 1 : LH_2 ON ORBIT PROPELLANT TANK DESIGN CONCEPT



ALTERNATE CONCEPT No. 1
- VENT LINE PENETRATION
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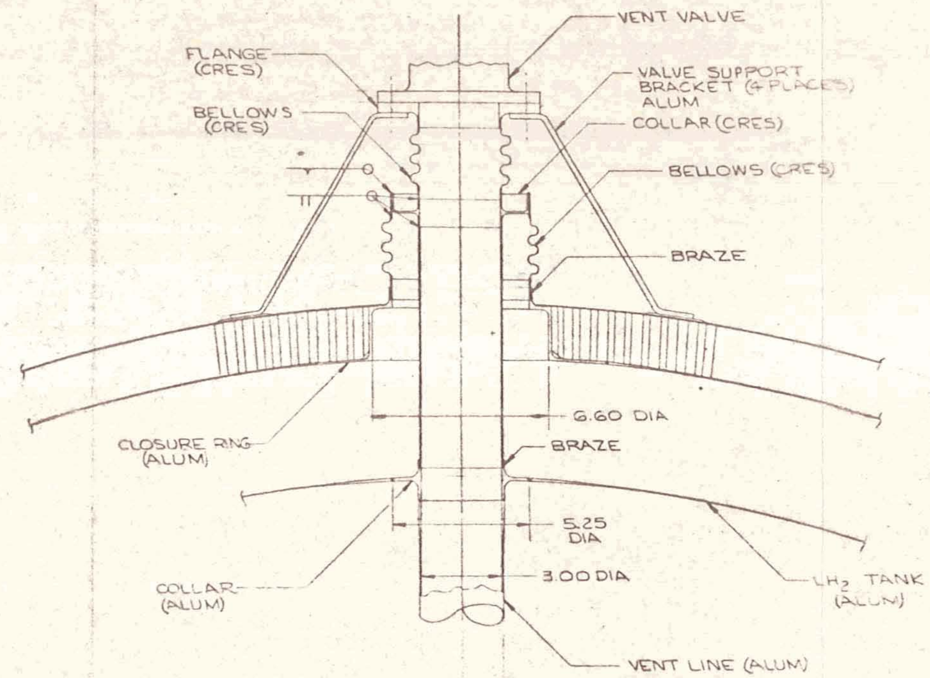

SECTION A-A
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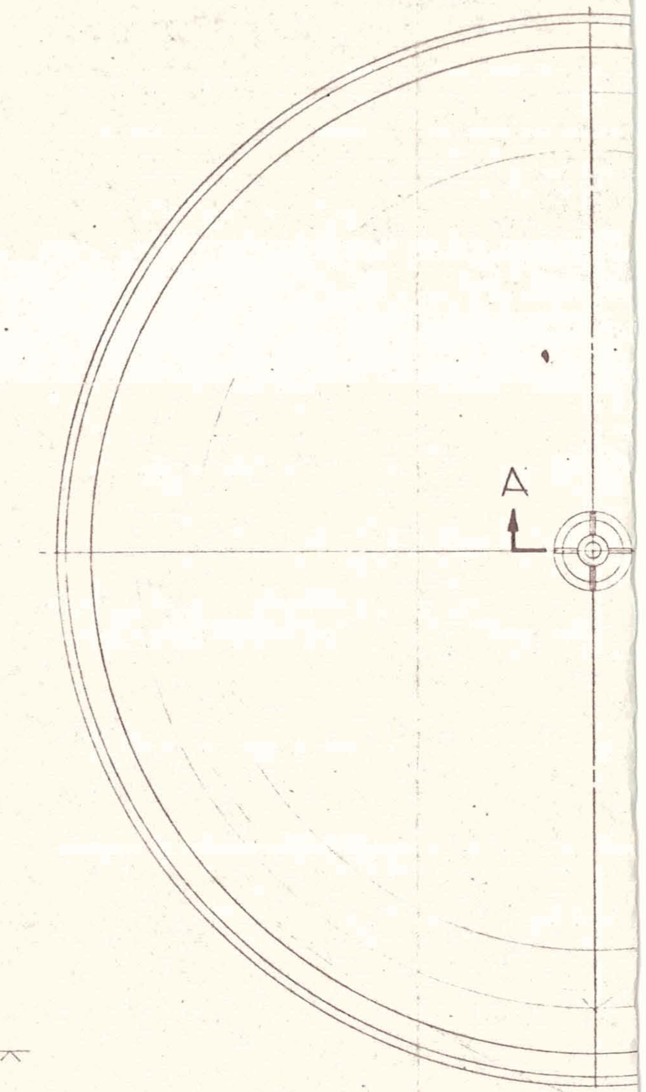

TOP VI
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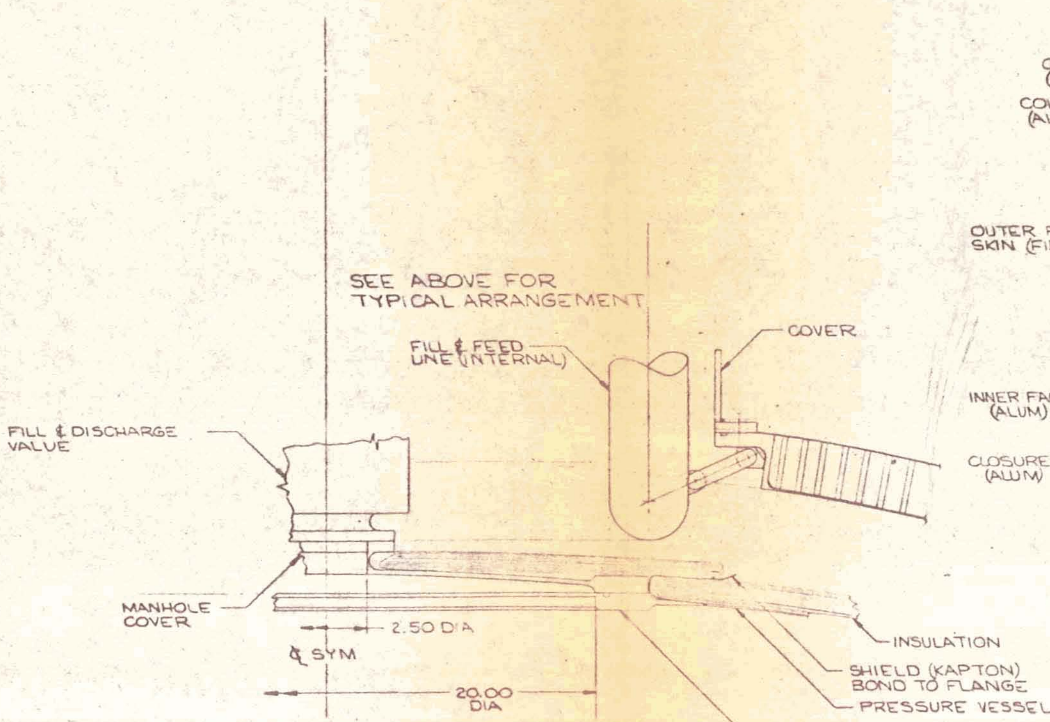

ALTERNATE CONCEPT No 1
FILL & DISCHARGE LINE
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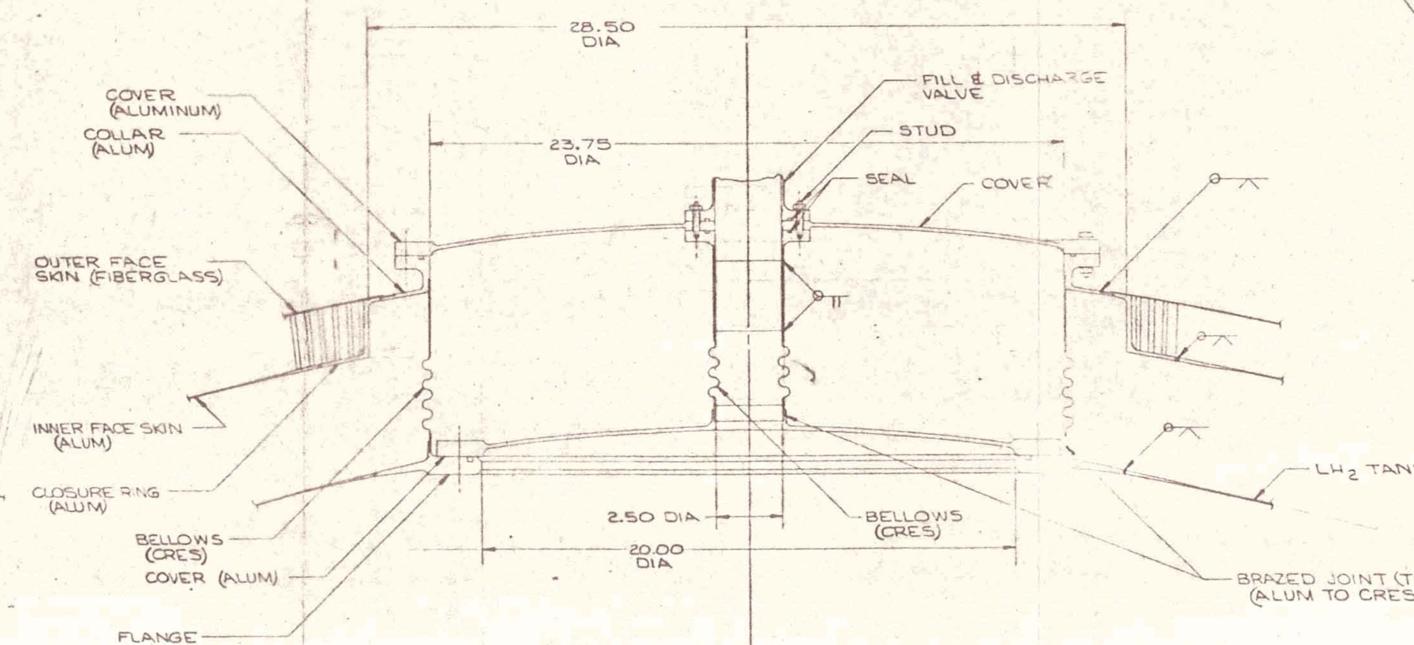


SECTION B-B
(SCALE 1/2)

part 2

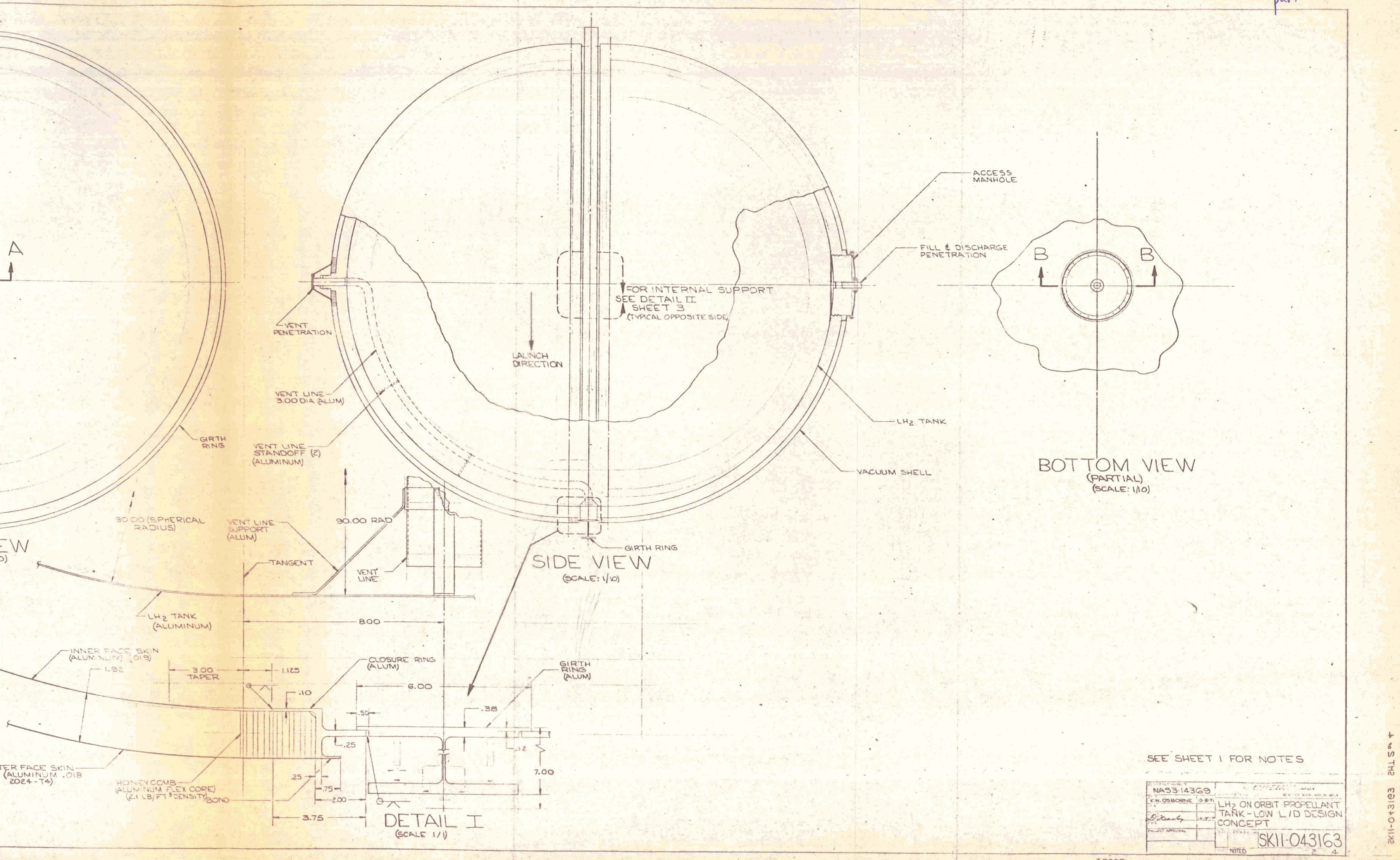


Figure 2

The alternate arrangement #1 for the plumbing penetrations relies on mechanical joints with low permeability seals for vacuum integrity of the insulation annulus. The length of the dry lines between the valves and the vacuum jackets will be determined by the heat leak requirements. Insulation external to the vacuum jacket is not necessary with this arrangement.

Pressure Vessel Support Systems

Two pressure vessel support systems for the low L/D LH_2 tank are shown in Figure 3 . The girth ring for the LH_2 tank described is aligned vertically in the orbiter. The support system shown in Detail III is applicable to the orientation. The system in Detail II applies to other LH_2 tank orientations in the orbiter as well.

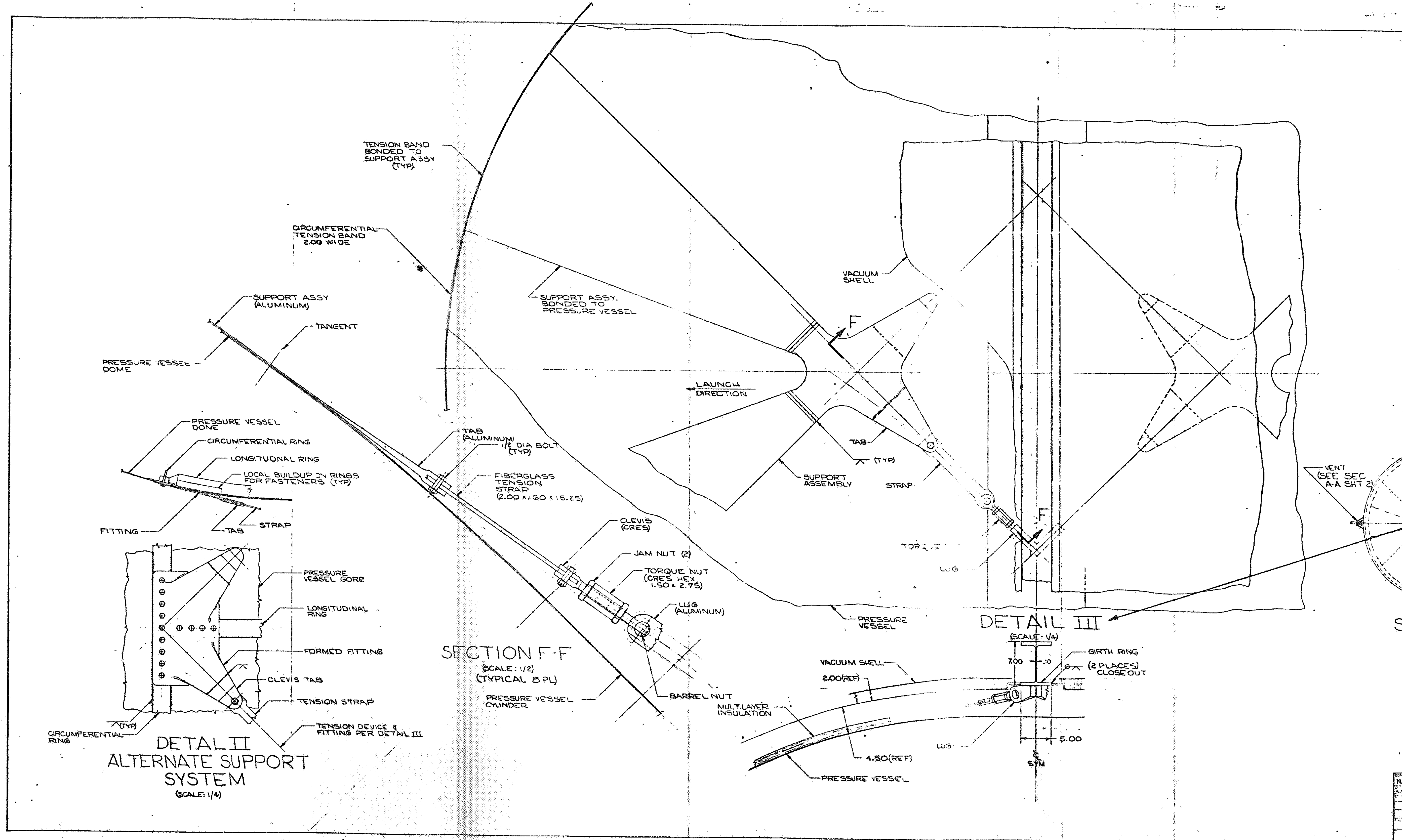
Detail III describes an aluminum strap net support system for the pressure vessel. These straps are bonded to the pressure vessel to prevent slipping. Eight fiberglass tension straps support the net from the vacuum jacket girth ring. Torque nuts pretension the straps after installation. A barrel nut arrangement at the girth ring provides for alignment.

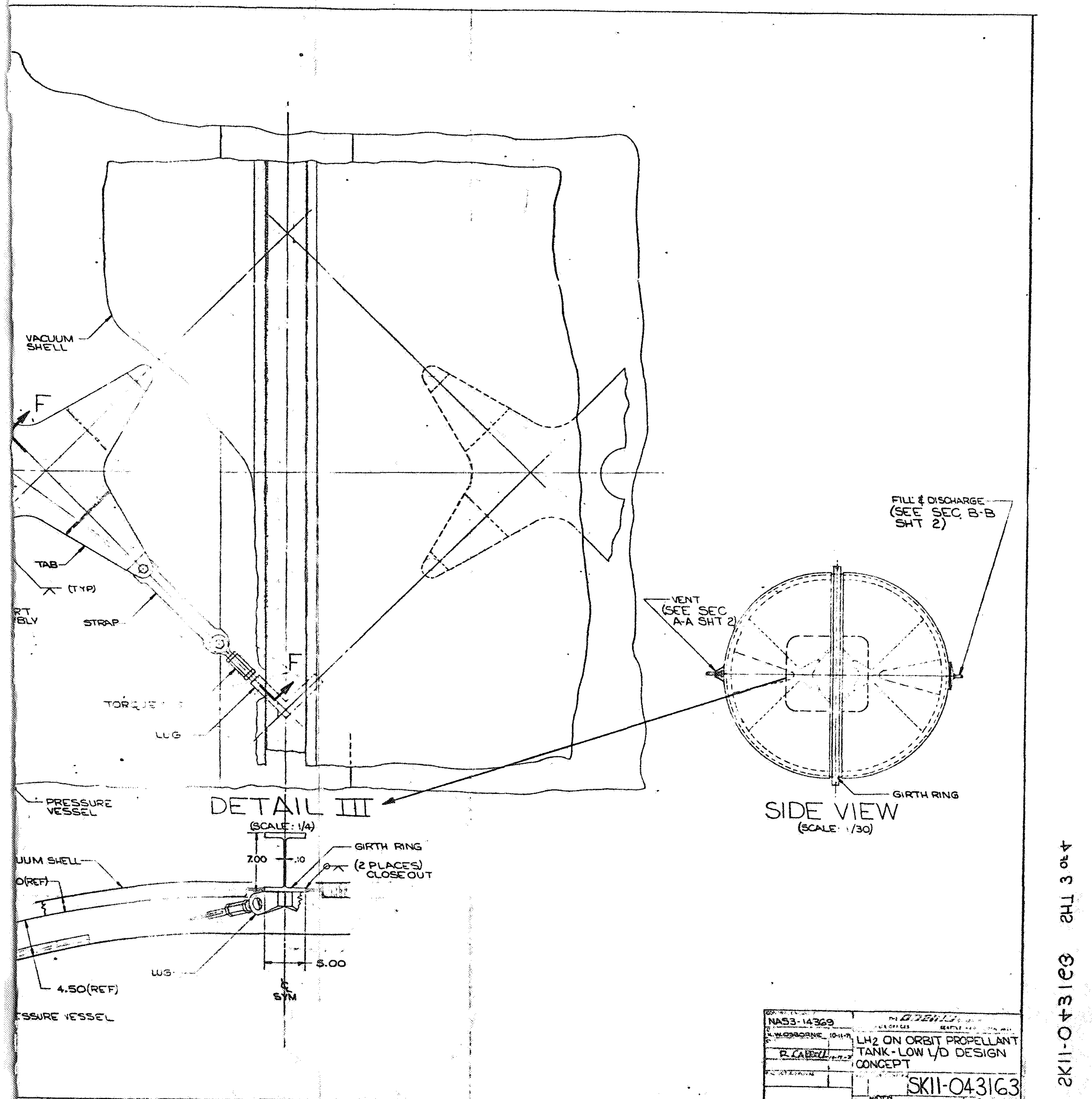
Detail II uses the eight fiberglass tension strap arrangement attaching to the girth ring. These tension straps attach to brackets bolted to the pressure vessel at four locations. Loads are distributed in the pressure vessel by two circumferential rings and two compression struts.

Titanium tension straps can be used as an alternative to the fiberglass tension strap.

Additional Studies

Study of the high L/D - LH_2 tank is in progress. Also, investigation of insulation arrangements for these configurations is underway.


TENSION BAND BONDED TO SUPPORT ASSY (TYP)
CIRCUMFERENTIAL TENSION BAND 2.00 WIDE
SUPPORT ASSY (ALUMINUM)
TANGENT
PRESSURE VESSEL DOME
SUPPORT ASSY. BONDED TO PRESSURE VESSEL
VACUUM SHELL
F
LAUNCH DIRECTION
TAB
(TYP)
SUPPORT ASSEMBLY
STRAP
LUG
PRESSURE VESSEL
VENT (SEE SEC A-A SHT 2)
PRESSURE VESSEL DOME
CIRCUMFERENTIAL RING
LONGITUDNAL RING
LOCAL BUILDUP ON RINGS FOR FASTENERS (TYP)
FITTING
TAB
STRAP
TAB (ALUMINUM)
1/2 DIA BOLT (TYP)
FIBERGLASS TENSION STRAP (2.00 x .60 x 15.25)
CLEVIS (CRES)
JAM NUT (2)
TORQUE NUT (CRES HEX 1.50 x 2.75)
LUG (ALUMINUM)
BARREL NUT
SECTION F-F
(SCALE: 1/2)
(TYPICAL 8 PL)
PRESSURE VESSEL CYLINDER
PRESSURE VESSEL GORE
LONGITUDINAL RING
FORMED FITTING
CLEVIS TAB
TENSION STRAP
TENSION DEVICE & FITTING PER DETAIL III
(TYP)
CIRCUMFERENTIAL RING
DETAIL II
ALTERNATE SUPPORT SYSTEM
(SCALE: 1/4)
DETAIL III
(SCALE: 1/4)
GIRTH RING
(2 PLACES) CLOSE OUT
7.00
.10
VACUUM SHELL
2.00(REF)
MULTILAYER INSULATION
4.50(REF)
PRESSURE VESSEL
LUG
5.00
SYM



VACUUM SHELL
F
TAB
(TYP)
STRAP
TORQUE
LUG
PRESSURE VESSEL
DETAIL III
(SCALE: 1/4)
GIRTH RING
(2 PLACES) CLOSEOUT
7.00
.10
5.00
SYM
4.50(REF)
LUG
FILL & DISCHARGE (SEE SEC. B-B SHT 2)
VENT (SEE SEC A-A SHT 2)
GIRTH RING
SIDE VIEW
(SCALE: 1/30)
NAS3-14369
R. CABELL
LH2 ON ORBIT PROPELLANT TANK - LOW L/D DESIGN CONCEPT
SKII-043163
NOTED
3
4
SKII-043163 SHT 3 of 4

Figure 3

Study Results

Those configurations will be used to evaluate weight penalties, thermal performance, manufacturing complexity and system reliability associated with the high and low L/D LH_2 tanks.

B.2 Outer Shell Study

Design and manufacturing studies are in progress investigating alternate approaches for manufacturing large diameter sandwich heads with thin gage face skins. The analytical trade studies with the 5056 aluminum flex-core show the aluminum face skin gages to range from 0.010 to 0.019 inches and the titanium from 0.010 to 0.012 inches. Major emphasis in the present studies is on vacuum tight skin fabrication techniques. Methods considered are compared on estimated costs, weight penalty and reliability.

Shells Formed from Large Blanks

One approach considered is spinning, bulge forming, or explosive sizing large blanks to contour, followed by selective chem-milling to meet thickness tolerances. Boeing experience has shown this approach to be costly and time consuming. However, this method does produce a highly reliable vacuum tight surface. For this reason the vacuum sealing face skin on the first 45-inch diameter test shell will be spun and chem-milled to thickness. Tests on this shell will provide baseline vacuum acquisition data to measure performance of other construction methods.

Adhesive Bonded Gores

A second approach is to adhesive bond stretch formed foil gores into a vacuum tight laminate of the required thickness. Three potential problem areas are evident with this approach. The adhesive may have an unacceptable outgassing rate into the vacuum annulus. Leakage into the vacuum annulus may result from bond line voids and/or permeation through the adhesive. Temperature cycling the sandwich shell may degrade the bond resulting in loss of structural and/or vacuum sealing integrity. An experimental evaluation of adhesive systems is necessary to investigate these questionable areas, before a final assessment of this approach can be made.

However, limited vacuum testing at Boeing on several adhesive systems indicate that this method has promise. One adhesive, PA 4459 (3M Co.) showed no measurable helium leakage during a 21 hour vacuum leak test. The test specimen consisted of a 1 mil thick bond line annulus, 0.50 inch wide (4.0-inch O.D. x 3.0 inch I.D.), between two 2024 aluminum plates. Vacuum pumping was by means of a leak detector cart coupled to the 3.0-inch I.D. perimeter. A plastic bag filled with helium covered the specimen. Part of the test time, 5-3/4 hours, was at 350°F; the remainder at room temperature.

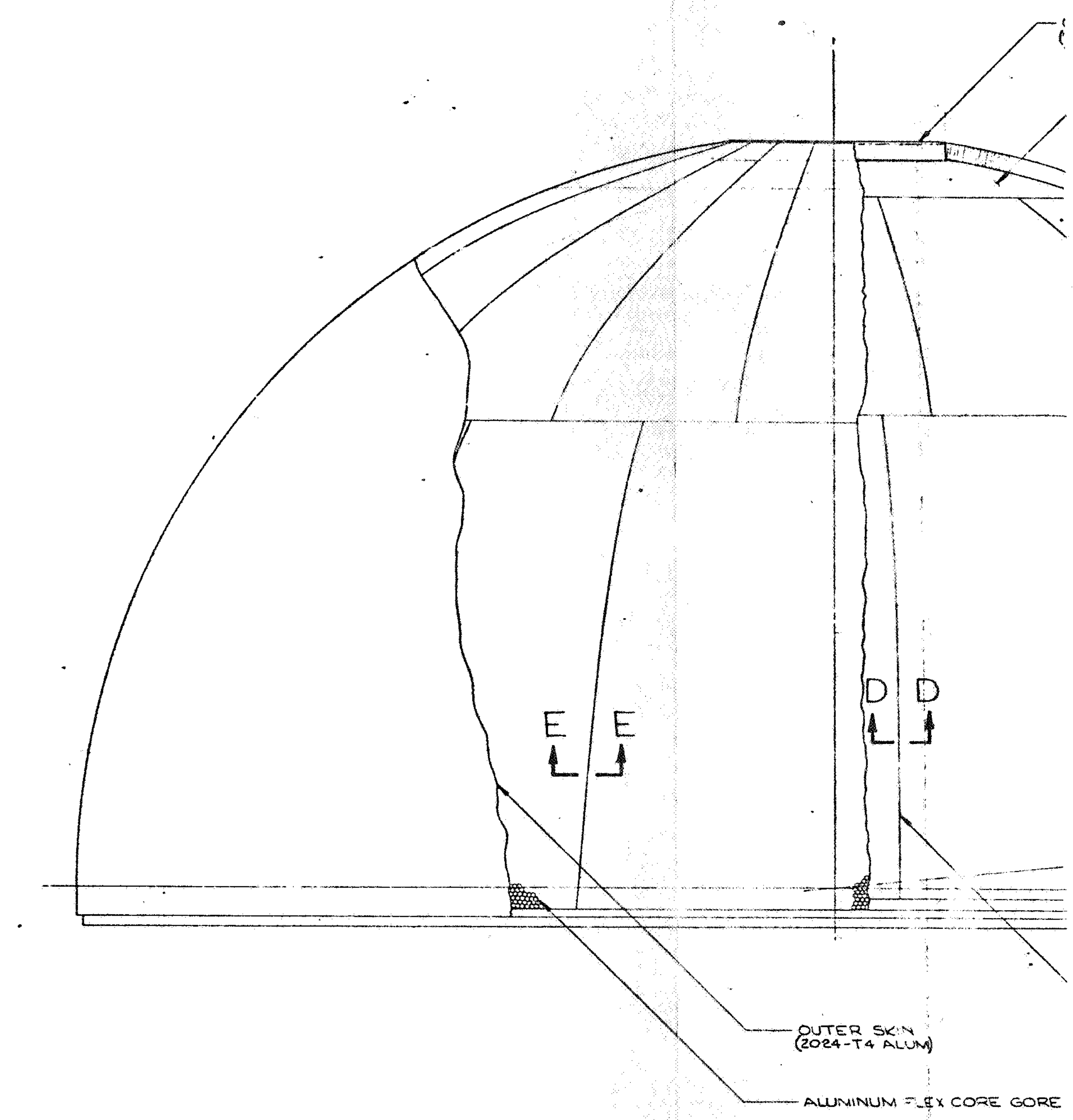
This approach also appears to offer better shell contour accuracy and lower fabrication costs than either the chem-milled spun shell or the welded gore shell. For these reasons the second 45-inch diameter test head will use laminated adhesive bonded 2024 aluminum foil gores for the vacuum tight face skin. The manufacturing and test data derived from this head will be used to assess feasibility of this approach.

Welded Preformed Gores

A third approach is welding preformed gore sections together. Figure 4 shows an outer shell arrangement using this approach. Extensive tooling is required for this method to hold adjacent gores firmly in place. Contour distortion due to welding may require an explosive sizing operation, or local use of the magnetic hammer. However, vacuum tight welded joints are highly reliable and should not degrade in service.

The aluminum flex-core and 2024 aluminum outer face skins are not perforated, as shown in Figure 4. The manufacturing difficulties associated with providing small diameter core and face skin perforations for sandwich shell venting are apparent. As well, the cycling of water moisture in and out of the cells may degrade the adhesive bonds. Alternatively, without venting, moisture trapped

PART I



SIDE VIEW~HEAD
(SCALE: 1/6)

PART 2

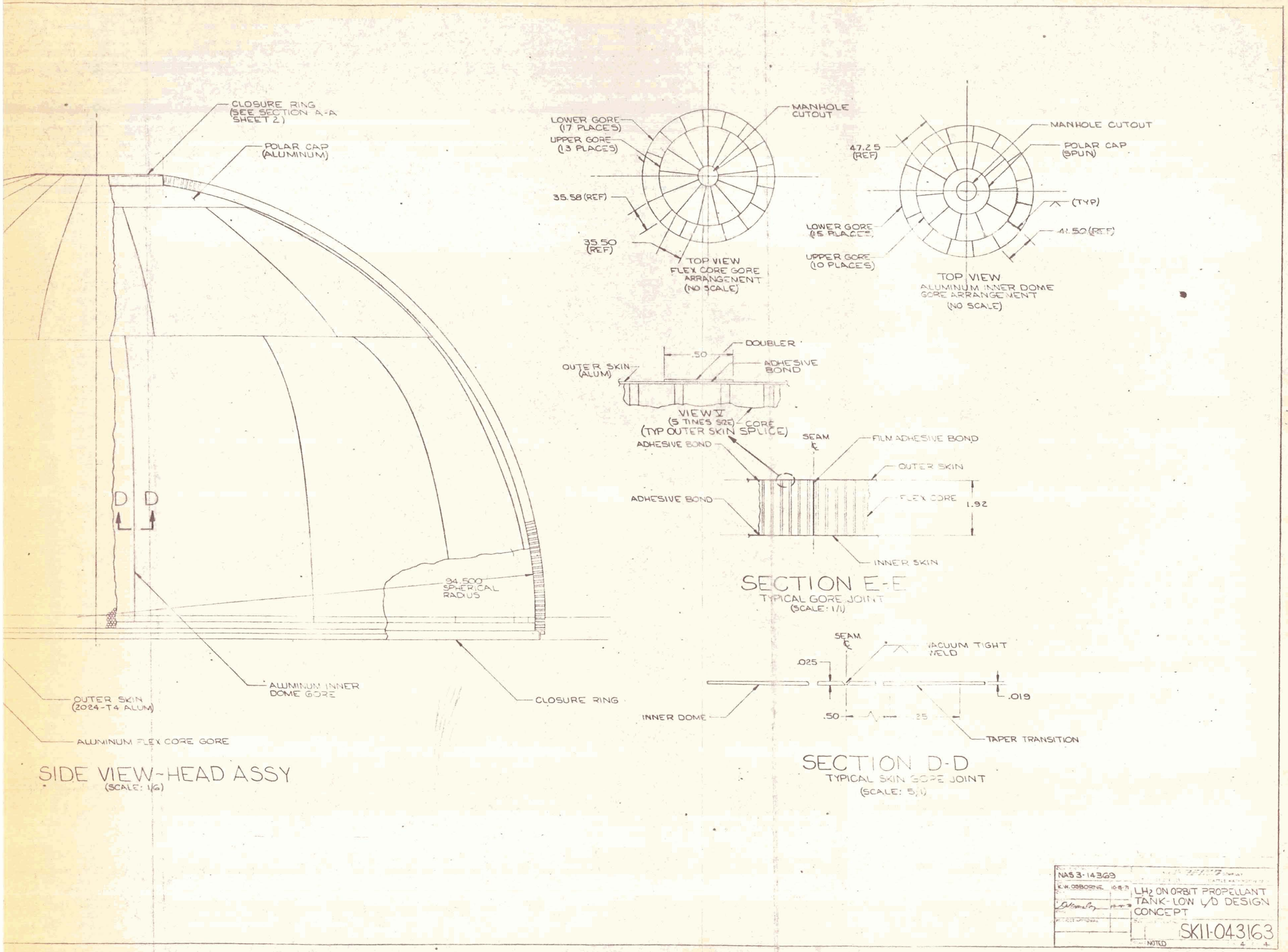


Figure 4

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in the cells will expand when heated and may excessively load the bonds. More data is required before recommendations for vented or non-vented sandwich shells can be made.

Results

A weight study of these designs was made. Baseline for comparison was the 0.019 inch aluminum vacuum face skin for a 15-ft spherical diameter shape. The weight ranges resulting from fabrication method and material tolerances was calculated for the welded gore and the bonded gore arrangements. Results are summarized below:

Fabrication Method	Material Thickness Tolerances (Inches)		Weight (Lb)	
			Min.	Max.
Base Line	0.019 (no material tolerances		193	193
Welded Gore	Base Metal (Heat Treated) Weld Lands (As Welded)	.024 .019 .033 .028	198	249
Adhesive Bonded Gores	2 Foils - Nominal Gages 0.010 and 0.012 Total Foil Bond Line	 .025 .019 .003 .002	204	271

Since tolerance control for the welded gore approach is by chem-milling, the gages noted above may be optimistic. The 0.005 tolerance may require excessive chem-milling time for the large gores involved. The foil tolerances for the bonded gore approach are per raw material specifications. The range of weight increase over the baseline shown above is between 3 and 40%. It seems reasonable to assume that the vacuum face skin weight increase can be held between 10 and 30%, at least with the bonded gore approach.

C. Shell Trade Studies

C.1 Preliminary Shell Construction Trades

Preliminary trades to determine trends and to assess candidate materials have been completed on the sandwich construction. Results of these were reported in the 1st quarterly report.

The waffle-grid construction computer program is in final checkout. The ring/stringer stiffened cylindrical shell computer program is in work.

C.2 Sandwich Shell Material Combination Trades

Material trades using eight different face skin combinations were reported in the 1st quarterly progress report. Cores used in these analyses were HRP and 5056 flex-core with properties based on data from Reference 1. These studies used a constant 2000 cu.ft. pressure vessel volume and a clearance of 4.5 inches between the pressure vessel and the outer vacuum jacket. In each sandwich configuration the metallic face skin was on the inside. A limit design external pressure of 14.7 psi was used with an ultimate factor of safety of 1.4. Launch loads were not considered, nor were weight allowances for fittings and joints made. A uniform shell temperature of 350°F was assumed. Appendices A, B & C of the 1st quarterly progress report described the OPTRAN Computer Program used to perform these trades and the stress analyses equations used in the analyses.

A probability of not failing under the design ultimate external pressure equal to 0.99 was used as a basis for the hemispherical head analyses. This required knockdown factors of approximately 1/6 for the hemispheres. The knockdown factor is the ratio of the expected test value to the classical theoretical value. The cylinders utilized knockdown factors of 0.90 for lateral pressure and 0.63 for hydrostatic axial compression. The analyses of Reference 2 were used. They are based on the solution of Kuenzi, Reference 3, and Yao, Reference 4.

All weights presented included the face skins, core and bonding adhesive. An adhesive weight of 0.0006 lb/in^2 for each surface was used.

Further studies have been completed and are discussed below: These used the same face skin and core combinations, but with the metallic face skin on the outside. Vacuum jackets were sized in these studies based on (a) the LH_2 pressure vessel volume of 2000 cu.ft. and (b) the LO_2 pressure vessel volume of 750 cu.ft. In both cases a clearance of 4.5 inches between the pressure vessel and the outer vacuum jacket was used. The other study parameters previously reported were not altered. The material properties used are unaltered from those previously reported.

Face Skin Trade Study - LH_2 Tank, HRP Core, Metallic Face Skin Outside

The results of this trade study are tabulated in Tables 2a, b and c. Total jacket weights of these designs are plotted vs L/D, the cylinder aspect ratio in Figure 5.

These data have been compared with the data from the 1st quarterly progress report on sandwich construction with HRP core and the metallic face skin on the inside. The results from this comparison are:

1) Cusps in the total jacket weight vs L/D curves occur in this latest data also.

2) No conclusive weight trends are obvious when the two sets of data are compared. The latest data shows improved weights in 16 out of the 24 cases studied. However, it is only in the glass/polyimide-aluminum and glass/epoxy-aluminum sandwich construction that a weight saving is shown with the new data for each L/D studied. With the other constructions studied the best weights are divided equally between the earlier and this latest data. Maximum weight savings shown between these two data is approximately 9%.

3) Placement of the metallic face skin does not significantly affect the weights, the core thickness and the face skin thicknesses.

4) The foregoing suggests that the location of the metallic face skin in the sandwich shell arrangement will be determined by manufacturing cost considerations, methods for achieving and measuring vacuum leak tightness, structural integrity and shell durability rather than by weight differences.

TABLE 2a: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT.				HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
				TOTAL JACKET WEIGHT	FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D	Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft³	LBS/IN² / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft³	LBS/IN² / Lbs
T_1 Boron/Epoxy	36	801	11.1	2126	.021 -14.0	.010 -13.3	.615	3/8 2.2	.00453 95	.040 -15.6	.022 -12.4	2.66	3/8 2.2	.00966 2031
	48	414	4.31	1737	.010 -28.7	.010 -26.6	1.09	3/16 4.0	.00546 193	.054 -15.6	.024 -12.3	2.77	3/8 2.2	.01106 1544
T_2 Aluminum	63	193	1.53	1271	.018 -22.6	.015 -20.9	1.49	3/8 3.2	.00677 397	.033 -29.2	.021 -22.0	2.34	1/4 3.5	.01048 874
	90	16	0.09	1095	.052 -15.5	.014 -14.8	1.87	3/8 3.2	.00874 995	.042 -29.1	.034 -22.3	1.23	3/16 4.0	.01049 100
T_1 Boron/Epoxy	36	801	11.1	2286	.015 -14.2	.010 -21.4	.583	3/8 3.2	.00497 104	.020 -25.8	.013 -29.8	2.78	1/4 3.5	.01033 2182
	48	414	4.31	1837	.013 -19.8	.010 -29.7	1.04	1/4 3.5	.00585 207	.032 -22.2	.016 -26.0	2.94	3/8 3.2	.01161 1630
T_2 Titanium	63	193	1.53	1270	.011 -27.0	.010 -40.5	1.37	3/16 4.0	.00682 399	.042 -25.1	.013 -29.8	2.22	3/8 3.2	.01046 871
	90	16	0.09	1121	.020 -27.3	.011 -40.9	1.94	3/16 4.0	.00893 1024	.044 -33.4	.012 -40.0	1.63	3/16 4.0	.01019 97

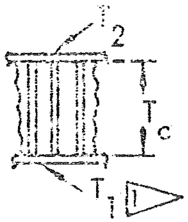
Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 2b: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT.			TOTAL JACKET WEIGHT	HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				CYL WEIGHT
 T_1 [1]	R In.	CYL. L In.	CYL. L/D	Lbs.	FACING THK & STRESS T_1 IN. / Stress ksi	FACING THK & STRESS T_2 IN. / Stress ksi	CORE T_c In.	CORE CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	FACING THK & STRESS T_1 IN. / Stress ksi	FACING THK & STRESS T_2 IN. / Stress ksi	CORE T_c In.	CORE CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Polyimide	36.	801	11.1	2908	.011 -6.8	.013 -28.0	1.18	1/4 3.5	.00567 121	.056 -6.3	.024 -22.2	3.00	3/8 3.2	.01323 2787
	48	414	4.31	2569	.015 -6.8	.016 -28.0	1.34	3/16 4.0	.00701 250	.090 -4.2	.051 -15.2	3.00	3/8 2.2	.01654 2319
T_2 Aluminum	63	193	1.53	1704	.016 -6.3	.024 -25.8	2.16	3/8 3.2	.00871 519	.048 -7.8	.038 -28.0	2.80	1/4 3.5	.01415 1185
	90	16	0.09	1490	.026 -6.8	.030 -28.0	2.77	1/4 3.5	.01162 1347	.029 -6.8	.072 -24.8	1.90	3/16 4.0	.01489 143
T_1 Glass/Polyimide	36	801	11.1	2957	.011 -5.5	.010 -36.7	.98	3/16 4.0	.00587 124	.046 -6.2	.018 -33.9	2.97	1/4 3.5	.01341 2833
	48	414	4.31	2700	.017 -6.1	.011 -41.2	1.27	3/16 4.0	.00710 253	.054 -3.3	.052 -18.5	3.00	3/8 2.2	.01730 2447
T_2 Titanium	63	193	1.53	1766	.020 -6.1	.014 -41.1	1.67	3/16 4.0	.00980 518	.043 -6.0	.038 -34.0	2.49	1/4 3.5	.01490 1248
	90	16	0.09	1585	.026 -5.1	.026 -34.1	2.60	1/4 3.5	.01242 1440	.027 -7.0	.045 -39.8	2.04	3/16 4.0	.01510 145

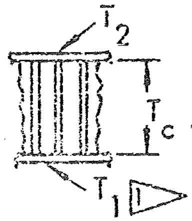
Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 2a OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT.				HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
					FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
 T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D	TOTAL JACKET WEIGHT Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Epoxy	36	801	11.1	3177	.013 -5.3	.013 -28.0	1.20	1/4 3.5	.00587 125	.066 -4.5	.030 -20.2	3.00	3/8 3.2	.01449 3052
	48	414	4.31	2832	.016 -5.3	.017 -28.0	1.57	1/4 3.5	.00725 259	.089 -3.8	.046 -17.2	3.00	1/4 3.5	.01836 2573
T_2 Aluminum	63	193	1.53	1784	.020 -5.3	.022 -27.6	2.05	1/4 3.5	.00901 534	.050 -5.7	.045 -25.8	3.00	3/8 3.2	.01489 1250
	90	16	0.09	1552	.029 -5.3	.030 -28.0	2.85	1/4 3.5	.01209 1402	.030 -5.4	.074 -24.7	2.60	3/8 3.2	.01560 150
T_1 Glass/Epoxy	36	801	11.1	3135	.012 -4.4	.010 -37.6	1.04	3/16 4.0	.00607 129	.055 -4.3	.022 -30.2	3.00	3/8 3.2	.01423 3006
	48	414	4.31	2741	.019 -4.8	.011 -41.2	1.32	3/16 4.0	.00740 263	.082 -3.8	.031 -26.8	3.00	3/8 3.2	.01966 2478
T_2 Titanium	63	193	1.53	1856	.021 -4.8	.015 -40.7	1.74	3/16 4.0	.00919 542	.039 -4.8	.037 -34.0	2.82	1/4 3.5	.01563 1314
	90	16	0.09	1576	.033 -4.8	.020 -41.2	2.38	3/16 4.0	.01236 1426	.029 -5.4	.047 -39.1	2.07	3/16 4.0	.01560 150

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

1 Boron/Epoxy - Aluminum
2 Boron/Epoxy - Titanium
3 Glass/Polyimide - Aluminum
4 Glass/Polyimide - Titanium
5 Glass/Epoxy - Aluminum
6 Glass/Epoxy - Titanium

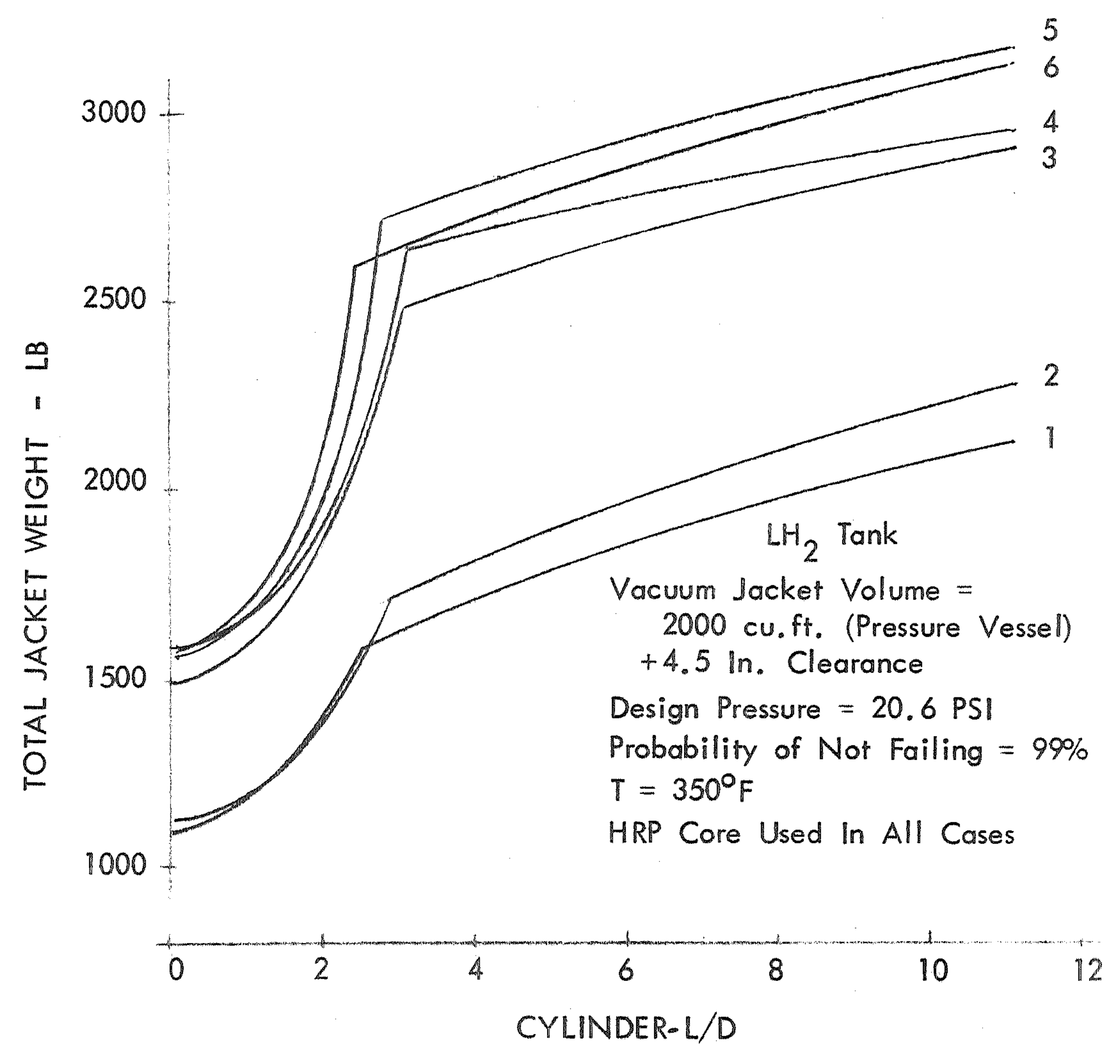


Figure 5 : VACUUM JACKET WEIGHTS VS CYLINDER L/D FOR SIX FACE MATERIALS AND HRP CORE

Face Skin Trade Study - LH_2 Tank, 5056 Aluminum Flex-Core, Metallic Face Skin Outside

The results of this trade study are tabulated in Tables 3a, b and c. Total jacket weights of these designs are plotted vs L/D, the cylinder aspect ratio in Figure 6.

These data have been compared with the data from the 1st quarterly progress report on sandwich construction with 5056 flex-core and the metallic face skin on the inside. The conclusions reached from this comparison are in agreement with those reached on the HRP core studies previously discussed.

TABLE 3a: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT.			TOTAL JACKET WEIGHT Lbs.	HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
					FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D		T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Boron/Epoxy	36.	801	11.1	1720	.010 -22.1	.010 -20.5	.623	.30 2.1	.00369 77	.018 -30.2	.016 -22.1	3.00	.30 2.1	.00776 1643
	48	414	4.31		.010 -27.6	.011 -25.6	.927	.30 2.1	.00415 146	DATA ERRATIC				
T_2 Aluminum	63	193	1.53	948	.013 -30.2	.011 -28.0	1.28	.30 2.1	.00485 283	.029 -33.9	.018 -25.5	2.37	.30 2.1	.00798 665
	90	16	0.09	793	.021 -30.2	.013 -28.0	1.85	.30 2.1	.00629 719	.047 -35.0	.012 -26.7	1.57	.30 2.1	.00779 74
T_1 Boron/Epoxy	36	801	11.1	1704	.010 -16.9	.010 -25.5	.554	.30 2.1	.00420 88	.015 -33.1	.011 -38.0	2.99	.30 2.1	.00762 1616
	48	414	4.31	1441	.010 -22.0	.010 -33.1	.824	.30 2.1	.00454 160	.026 -26.5	.015 -30.9	3.00	.30 2.1	.00911 1281
T_2 Titanium	63	193	1.53	955	.010 -26.7	.011 -40.0	1.20	.30 2.1	.00516 302	.028 -35.0	.011 -41.4	2.31	.30 2.1	.00784 653
	90	16	0.09	813	.018 -28.4	.011 -42.6	1.73	.30 2.1	.00644 738	.043 -34.8	.011 -41.8	1.41	.30 2.1	.00786 75

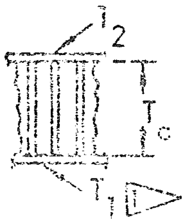
Note: Total Weight includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 3b: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES



SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT. R In.	CYL. L In.	CYL. L/D	TOTAL JACKET WEIGHT Lbs.	HEMISPHERICAL HEADS FACING THK & STRESS T_1 IN. / Stress ksi	HEMISPHERICAL HEADS FACING THK & STRESS T_2 IN. / Stress ksi	HEMISPHERICAL HEADS CORE T_c In.	HEMISPHERICAL HEADS CORE CELL SIZE / Weight Lbs/Ft³	TOTAL WEIGHT OF TWO HEADS LBS/IN² / Lbs	CYLINDER FACING THK & STRESS T_1 IN. / Stress ksi	CYLINDER FACING THK & STRESS T_2 IN. / Stress ksi	CYLINDER CORE T_c In.	CYLINDER CORE CELL SIZE / Weight Lbs/Ft³	CYL WEIGHT LBS/IN² / Lbs
T_1 Glass/Polyimide, T_2 Aluminum	36	801	11.1	2298	.010 / -6.8	.013 / -28.0	.986	.30 / 2.1	.00443 / 94	.047 / -7.2	.022 / -25.0	3.00	.30 / 2.1	.01046 / 2204
	48	414	4.31	2312	.014 / -6.8	.016 / -28.0	1.26	.30 / 2.1	.00539 / 192	DATA ERRATIC				
	63	193	1.53	1352	.015 / -6.8	.022 / -28.0	1.71	.30 / 2.1	.00657 / 388	.035 / -7.8	.042 / -28.0	2.91	.30 / 2.1	.01147 / 964
	90	16	0.09	1127	.024 / -6.8	.030 / -28.0	2.31	.30 / 2.1	.00873 / 1008	.023 / -6.8	.074 / -24.8	1.80	.30 / 2.1	.01242 / 119
T_1 Glass/Polyimide, T_2 Titanium	36	801	11.1	2270	.010 / -5.4	.010 / -36.3	.917	.30 / 2.1	.00469 / 99	.043 / -7.2	.015 / -39.6	3.00	.30 / 2.1	.01029 / 2171
	48	414	4.31	2067	.011 / -5.9	.012 / -39.8	1.35	.30 / 2.1	.00560 / 200	.067 / -5.9	.023 / -32.7	3.00	.30 / 2.1	.01333 / 1867
	63	193	1.53	1350	.013 / -6.5	.014 / -43.7	1.81	.30 / 2.1	.00666 / 394	.030 / -7.5	.029 / -42.4	2.80	.30 / 2.1	.01137 / 956
	90	16	0.09	1139	.020 / -6.5	.020 / -43.7	2.45	.30 / 2.1	.00882 / 1021	.022 / -7.4	.043 / -42.1	2.12	.30 / 2.1	.01232 / 118

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 3c: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 2000 CU.FT. R In.	CYL. L In.	CYL. L/D	TOTAL JACKET WEIGHT Lbs.	HEMISPHERICAL HEADS FACING THK & STRESS T_1 IN. / Stress ksi	HEMISPHERICAL HEADS FACING THK & STRESS T_2 IN. / Stress ksi	HEMISPHERICAL HEADS CORE T_c in.	HEMISPHERICAL HEADS CORE CELL SIZE / Weight Lbs/Ft^3	TOTAL WEIGHT OF TWO HEADS LBS/IN^2 / Lbs	CYLINDER FACING THK & STRESS T_1 IN. / Stress ksi	CYLINDER FACING THK & STRESS T_2 IN. / Stress ksi	CYLINDER CORE T_c In.	CYLINDER CORE CELL SIZE / Weight Lbs/Ft^3	CYL WEIGHT LBS/IN^2 / Lbs
T_1 [1] Glass/Epoxy	36	801	11.1	2534	.011 -5.3	.013 -28.0	1.06	.30 2.1	.00459 98	.057 -5.2	.026 -23.1	3.00	.30 2.1	.01157 2436
	48	414	4.31	2315	.011 -5.3	.018 -28.0	1.48	.30 2.1	.00560 200	.084 -4.2	.042 -18.7	3.00	.30 2.1	.01511 2115
T_2 Aluminum	63	193	1.53	1436	.017 -5.3	.022 -28.0	1.82	.30 2.1	.00685 405	.045 -6.2	.042 -28.0	3.00	.30 2.1	.01227 1031
	90	16	0.09	1178	.023 -5.3	.031 -28.0	2.57	.30 2.1	.00911 1055	.020 -5.4	.076 -24.8	2.08	.30 2.1	.01277 123
T_1 Glass/Epoxy	36	801	11.1	2466	.010 -4.4	.010 -37.1	1.02	.30 2.1	.00482 102	.054 -5.5	.016 -38.3	3.00	.30 2.1	.01122 2364
	48	414	4.31	2260	.012 -5.1	.011 -43.8	1.45	.30 2.1	.00565 202	.077 -4.3	.027 -30.4	3.00	.30 2.1	.01468 2058
T_2 Titanium	63	193	1.53	1445	.020 -5.9	.012 -49.9	1.75	.30 2.1	.00768 452	.035 -6.1	.028 -43.7	2.93	.30 2.1	.01181 993
	90	16	0.09	1198	.023 -5.1	.020 -43.7	2.57	.30 2.1	.00920 1066	.028 -5.6	.045 -40.8	1.88	.30 3.1	.01377 132

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

1 Boron/Epoxy - Aluminum (Not Shown - Data Erratic)

2 Boron/Epoxy - Titanium

3 Glass/Polyimide - Aluminum (Not Shown - Data Erratic)

4 Glass/Polyimide - Titanium

5 Glass/Epoxy - Aluminum

6 Glass/Epoxy - Titanium

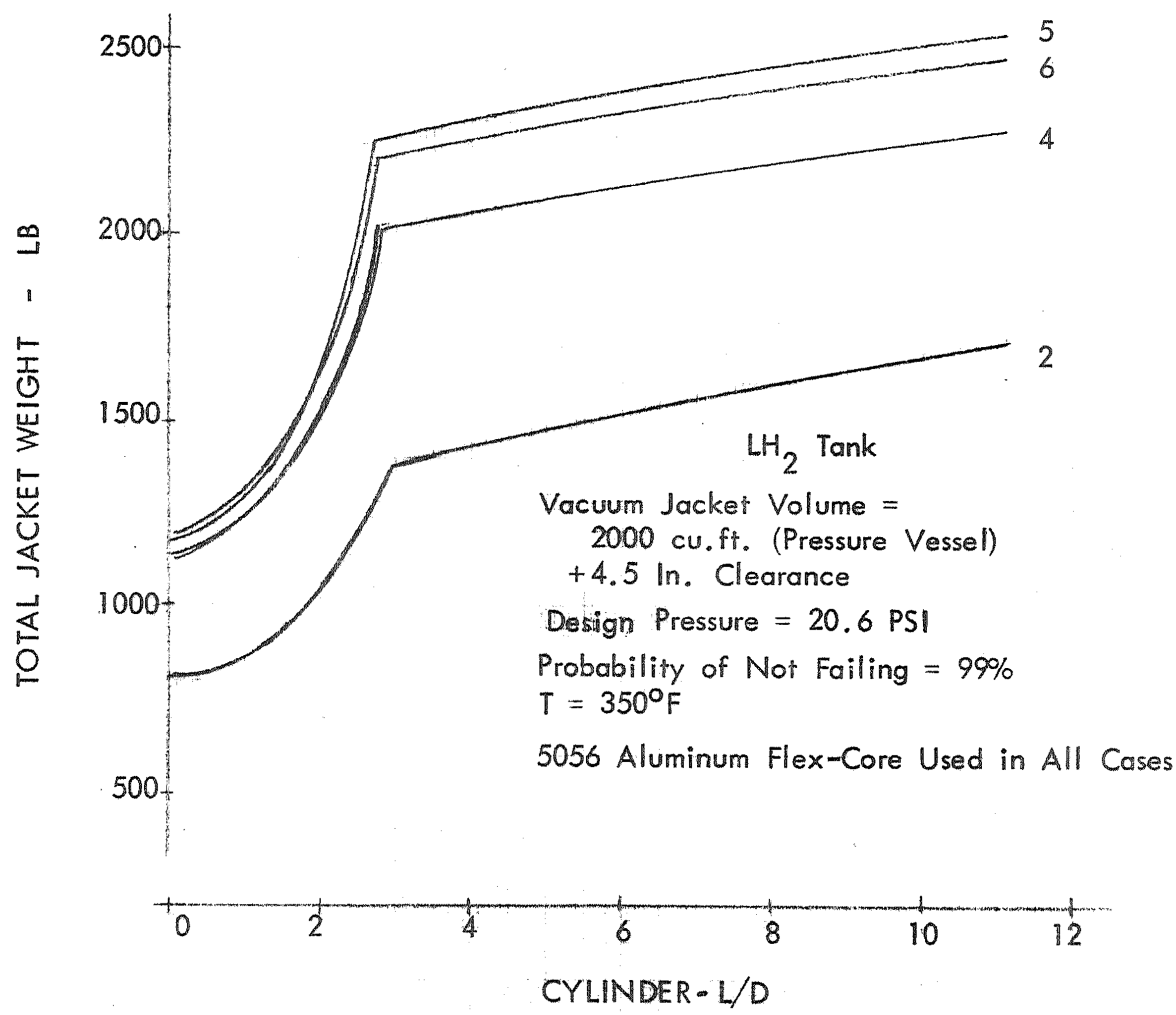


Figure 6: VACUUM JACKET WEIGHTS VS CYLINDER L/D FOR SIX FACE MATERIALS AND 5056 ALUMINUM FLEX-CORE

Face Skin Trade Study - LO_2 Tank, HRP Core, Metallic Face Skin Outside

The differences in the study parameters between the LO_2 tank and the previously discussed LH_2 tank are:

	LO_2 TANK	LH_2 TANK
Volume	750 cu. ft.	2000 cu. ft.
Diameter Range	4 ft - 10 ft	6 ft - 15 ft

The results of this trade study are tabulated in Tables 4a, b and c. Total jacket weights of these designs are plotted vs L/D in Figure 7. The cusp is not as pronounced in these curves as in the case with the LH_2 shell. Indeed, a cusp may not exist in this smaller volume tank. A reasonably fair curve can be drawn through the data points. It was considered appropriate in view of the LH_2 jacket curves to assume that a cusp would also exist in the LO_2 jacket curves. Further analysis is necessary to clarify this matter.

Results from this study are:

1) The high stiffness of boron/epoxy results in substantial weight savings over other material combinations.

2) Aluminum face skins result in lighter weight than titanium face skins in all cases studied.

TABLE 4a: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 750 CU. FT.				HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
					FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D	TOTAL JACKET WEIGHT Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft³	LBS/IN² / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft³	LBS/IN² / Lbs
T_1 Boron/Epoxy	24	684	14.3	950	.013 -13.6	.010 -12.9	.397	3/8 2.2	.00363 38	.031 -15.5	.012 -12.4	2.02	3/8 2.2	.00722 912
	30	418	6.97	837	.011 -17.6	.011 -16.4	.598	3/8 3.2	.00417 64	.033 -15.6	.019 -12.4	2.15	3/8 2.2	.00828 773
T_2 Aluminum	42	178	2.12	572	.025 -14.0	.010 -13.4	.736	3/8 2.2	.00501 138	.026 -25.9	.017 -19.5	1.85	3/8 3.2	.00819 434
	60	35	0.29	451	.018 -22.7	.014 -21.0	1.44	3/8 3.2	.00652 349	.027 -35.0	.015 -26.7	1.07	3/16 4.0	.00717 102
T_1 Boron/Epoxy	24	684	14.3	992	.010 -11.8	.010 -17.9	.352	3/8 3.2	.00419 43	.015 -22.4	.011 -26.1	1.84	3/8 3.2	.00748 949
	30	418	6.97	872	.011 -13.6	.010 -20.5	.481	3/8 3.2	.00454 69	.017 -25.1	.012 -29.2	2.31	3/8 3.2	.00855 803
T_2 Titanium	42	178	2.12	581	.011 -18.9	.010 -28.4	.885	1/4 3.5	.00540 150	.025 -25.2	.012 -29.9	1.71	3/8 3.2	.00814 431
	60	35	0.29	459	.017 -19.8	.012 -29.7	1.27	3/8 3.2	.00667 356	.027 -34.0	.010 -40.7	1.05	3/16 4.0	.00728 103

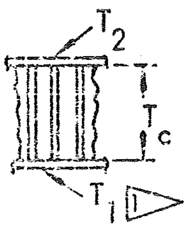
Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 4b: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 750 CU. FT.			TOTAL JACKET WEIGHT Lbs.	HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
	R In.	CYL. L In.	CYL. L/D		FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
					T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Polyimide, T_2 Aluminum	24	684	14.3	1246	.010 -5.8	.010 -24.3	.650	3/16 4.0	.00443 46	.028 -7.4	.017 -25.6	2.43	3/8 3.2	.00940 1200
	30	418	6.97	1110	.010 -6.8	.011 -28.0	.992	1/4 3.5	.00500 77	.036 -7.4	.020 -25.7	2.82	3/8 3.2	.01096 1033
	42	178	2.12	760	.015 -6.8	.014 -28.0	1.14	3/16 4.0	.00633 177	.036 -7.2	.029 -25.7	2.29	3/8 3.2	.01093 583
	60	35	0.29	592	.020 -6.7	.020 -28.0	1.60	3/16 4.0	.00832 447	.022 -7.7	.043 -28.0	1.56	1/4 3.5	.01018 145
T_1 Glass/Polyimide, T_2 Titanium	24	684	14.3	1292	.010 -3.9	.010 -26.1	.581	3/16 4.0	.00487 51	.030 -5.5	.015 -30.2	2.12	3/8 3.2	.00975 1241
	30	418	6.97	1167	.012 -2.8	.018 -18.5	.780	3/8 2.2	.00592 91	.035 -6.2	.016 -33.9	2.53	1/4 3.5	.01144 1076
	42	178	2.12	794	.014 -6.1	.010 -40.9	1.15	3/16 4.0	.00644 180	.040 -6.0	.022 -33.8	1.92	1/4 3.5	.01154 614
	60	35	0.29	606	.020 -6.1	.014 -41.2	1.58	3/16 4.0	.00845 454	.024 -7.1	.029 -40.9	1.33	3/16 4.0	.01065 152

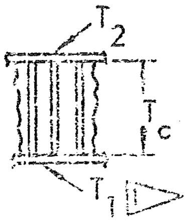
Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 4c OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE HRP CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 750 CU.FT.			TOTAL JACKET WEIGHT	HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
					FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
 T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D	Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Epoxy	24	684	14.3	1343	.022 -2.6	.017 -13.9	.497	3/16 4.0	.00570 59	.032 -5.9	.018 -25.6	2.57	3/8 3.2	.01004 1284
	30	418	6.97	1184	.011 -5.3	.011 -28.0	.908	3/16 4.0	.00520 80	.030 -3.6	.042 -15.8	3.11	3/8 2.2	.01155 1104
T_2 Aluminum	42	178	2.12	805	.016 -5.3	.015 -28.0	1.20	3/16 4.0	.00659 184	.040 -5.7	.030 -25.7	2.44	3/8 3.2	.01163 621
	60	35	0.29	623	.016 -4.9	.024 -25.8	2.13	3/8 3.2	.00867 471	.025 -6.0	.043 -28.0	1.49	3/16 4.0	.01070 152
T_1 Glass/Epoxy	24	684	14.3	1370	.010 -3.2	.010 -27.0	.754	1/4 3.5	.00506 53	.029 -4.4	.017 -30.2	2.33	3/8 3.2	.01030 1317
	30	418	6.97	1226	.011 -3.8	.010 -32.3	.824	3/16 4.0	.00549 84	.041 -4.9	.017 -33.8	2.62	1/4 3.5	.01213 1142
T_2 Titanium	42	178	2.12	831	.016 -4.8	.010 -41.2	1.19	3/16 4.0	.00669 187	.036 -4.8	.024 -34.0	2.17	1/4 3.5	.01207 644
	60	35	0.29	630	.021 -4.8	.014 -41.1	1.67	3/16 4.0	.00882 475	.023 -5.6	.030 -41.2	1.40	3/16 4.0	.01087 155

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

1 Boron/Epoxy - Aluminum
2 Boron/Epoxy - Titanium
3 Glass/Polyimide - Aluminum
4 Glass/Polyimide - Titanium
5 Glass/Epoxy - Aluminum
6 Glass/Epoxy - Titanium

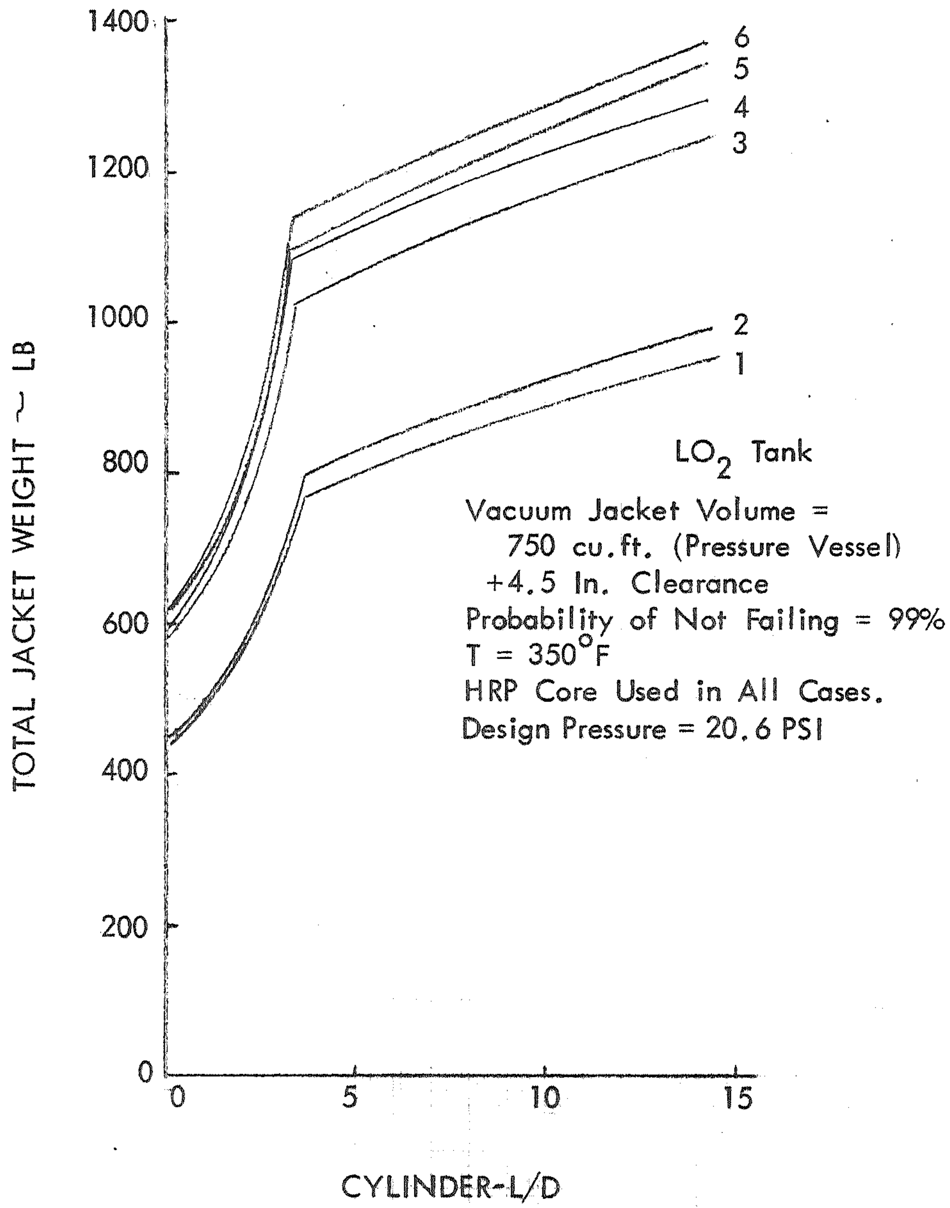


Figure 7: VACUUM JACKET WEIGHTS VS CYLINDER L/D FOR SIX FACE MATERIALS AND HRP CORE

Face Skin Trade Study - LO_2 Tank, 5056 Flex-Core, Metallic Face Skin Outside

The results of this trade study are tabulated in Tables 5a, b and c. Total jacket weights of these designs are plotted vs L/D in Figure 8. Again, a cusp has been shown in these curves, although it is not conclusive at this stage in the analysis that a cusp does exist.

This trade study shows:

1) The significance of core shear properties on the weight of vacuum jacket designs. The use of a low shear modulus core, i.e., HRP, results in a severe weight penalty for the vacuum jacket designs. This was also shown in the LH_2 jacket trade studies.

2) Except in the boron/epoxy-aluminum sandwich arrangement, the titanium face skins generally result in lighter weight. Comparing this with the LO_2 tank - HRP core data, suggests that increasing the core shear modulus has a greater impact on the efficiency of the titanium skin than it does on the aluminum skin. This was also shown in the LH_2 jacket trade studies.

,TABLE 5a:OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 750 CU.FT.				HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
T_2, T_c, T_1 [1]	R In.	CYL. L In.	CYL. L/D	TOTAL JACKET WEIGHT Lbs.	FACING THK & STRESS: T_1 IN. / Stress ksi	FACING THK & STRESS: T_2 IN. / Stress ksi	CORE: T_c In.	CORE: CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	FACING THK & STRESS: T_1 IN. / Stress ksi	FACING THK & STRESS: T_2 IN. / Stress ksi	CORE: T_c In.	CORE: CELL SIZE / Weight Lbs/Ft^3	CYL WEIGHT LBS/IN^2 / Lbs
T_1 Boron/Epoxy, T_2 Aluminum	24	684	14.3	777	.010 -15.5	.010 -14.4	.368	.30 2.1	.00338 35	.012 -31.6	.011 -23.1	2.19	.30 2.1	.00582 742
	30	418	6.97	688	.010 -18.7	.010 -17.4	.432	.30 3.1	.00371 56	.015 -31.5	.013 -23.1	2.58	.30 2.1	.00670 632
	42	178	2.12	451	.010 -25.0	.010 -23.2	.770	.30 2.1	.00390 108	.019 -35.0	.013 -26.1	2.10	.30 2.1	.00645 343
	60	35	0.29	332	.012 -30.1	.011 -28.0	1.21	.30 2.1	.00470 251	.030 -35.0	.011 -26.7	1.02	.30 2.1	.00574 81
T_1 Boron/Epoxy, T_2 Titanium	24	684	14.3	788	.010 -11.9	.010 -17.9	.354	.30 2.1	.00397 41	.010 -28.7	.010 -33.2	1.91	.30 2.1	.00587 747
	30	418	6.97	688	.010 -14.4	.010 -21.7	.443	.30 2.1	.00407 62	.013 -30.4	.010 -35.2	2.35	.30 2.1	.00665 626
	42	178	2.12	462	.010 -19.5	.010 -29.3	.681	.30 2.1	.00436 121	.015 -35.0	.011 -41.2	1.91	.30 2.1	.00641 341
	60	35	0.29	352	.010 -25.9	.011 -38.9	1.13	.30 2.1	.00503 268	.025 -35.0	.011 -42.1	.915	.30 2.1	.00593 84

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

TABLE 5b: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY 3
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES

SANDWICH	GEOMETRY 2 VOL = 750 CU.FT.				HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
				TOTAL JACKET WEIGHT	FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
T_2, T_c, T_1 1	R In.	CYL. L In.	CYL. L/D	Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Polyimide, T_2 Aluminum	24	684	14.3	990	.010 -5.7	.010 - 23.6	.580	.30 2.1	.00366 38	.024 -8.1	.016 -28.0	2.41	.30 2.1	.00746 952
	30	418	6.97	880	.010 -6.5	.011 -27.0	.794	.30 2.1	.00399 61	.030 -8.1	.019 -28.0	2.84	.30 2.1	.00868 819
	42	178	2.12	617	.010 -6.8	.015 -28.0	1.20	.30 2.1	.00490 137	.023 -7.9	.030 -28.0	2.59	.30 2.1	.00895 480
	60	35	0.29	464	.015 -6.8	.021 -28.0	1.62	.30 2.1	.00633 341	.017 -7.7	.044 -27.9	1.44	.30 2.1	.00859 123
T_1 Glass/Polyimide, T_2 Titanium	24	684	14.3	994	.010 -3.9	.010 -26.1	.507	.30 2.1	.00414 43	.019 -8.0	.011 -43.2	2.50	.30 2.1	.00741 951
	30	418	6.97	878	.010 -4.7	.010 -31.6	.704	.30 2.1	.00438 67	.027 -8.0	.013 -43.2	2.78	.30 2.1	.00859 811
	42	178	2.12	616	.011 -5.9	.011 -39.7	1.12	.30 2.1	.00507 142	.033 -7.6	.018 -42.8	2.08	.30 2.1	.00890 474
	60	35	0.29	461	.015 -6.5	.013 -43.7	1.62	.30 2.1	.00640 345	.017 -10.5	.020 -60.3	1.44	.30 3.1	.00812 116

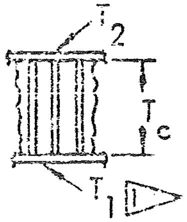
Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

1 Inner Face Skin

2 Pressure Vessel

3 Designed with 4.5" Clearance Around Pressure Vessel

TABLE 5c: OPTIMUM VACUUM JACKET DESIGNS FOR 99% PROBABILITY [3]
USING ALLOWABLE 5056 ALUMINUM FLEX-CORE PROPERTIES

SANDWICH	GEOMETRY [2] VOL = 750 CU.FT.			TOTAL JACKET WEIGHT	HEMISPHERICAL HEADS				TOTAL WEIGHT OF TWO HEADS	CYLINDER				
					FACING THK & STRESS		CORE			FACING THK & STRESS		CORE		CYL WEIGHT
 T_2 T_c T_1 [1]	R. In.	CYL. L In.	CYL. L/D	Lbs.	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs	T_1 IN. / Stress ksi	T_2 IN. / Stress ksi	T_c In.	CELL SIZE / Weight Lbs/Ft^3	LBS/IN^2 / Lbs
T_1 Glass/Epoxy T_2 Aluminum	24	684	14.3	1060	.010 -4.6	.010 -24.3	.636	.30 2.1	.00374 39	.028 -6.4	.016 -28.0	2.57	.30 2.1	.00798 1021
	30	418	6.97	947	.010 -5.3	.011 -27.7	.867	.30 2.1	.00411 63	.029 -6.4	.021 -28.0	3.20	.30 2.1	.00931 884
	42	178	2.12	667	.013 -5.3	.015 -28.0	1.14	.30 3.1	.00571 159	.029 -6.2	.030 -28.0	2.63	.30 2.1	.00948 508
	60	35	0.29	484	.014 -5.3	.022 -28.0	1.84	.30 2.1	.00661 357	.017 -6.1	.045 -28.0	1.61	.30 2.1	.00887 127
T_1 Glass/Epoxy T_2 Titanium	24	684	14.3	1046	.010 -3.1	.010 -26.8	.555	.30 2.1	.00420 44	.024 -6.3	.011 -43.4	2.56	.30 2.1	.00782 1002
	30	418	6.97	933	.010 -3.8	.010 -32.6	.776	.30 2.1	.00447 69	.028 -6.3	.014 -43.4	3.04	.30 2.1	.00911 864
	42	178	2.12	643	.010 -4.8	.011 -40.8	1.28	.30 2.1	.00523 147	.028 -6.2	.019 -43.6	2.45	.30 2.1	.00926 496
	60	35	0.29	480	.015 -5.1	.014 -43.8	1.76	.30 2.1	.00666 360	.020 -8.3	.020 -60.3	1.48	.30 3.1	.00844 120

Note: Total Weight Includes Face Skins, Core, and Bonding Adhesive

[1] Inner Face Skin

[2] Pressure Vessel

[3] Designed with 4.5" Clearance Around Pressure Vessel

1 Boron/Epoxy - Aluminum
2 Boron/Epoxy - Titanium
3 Glass/Polyimide - Aluminum
4 Glass/Polyimide - Titanium
5 Glass/Epoxy - Aluminum
6 Glass/Epoxy - Titanium

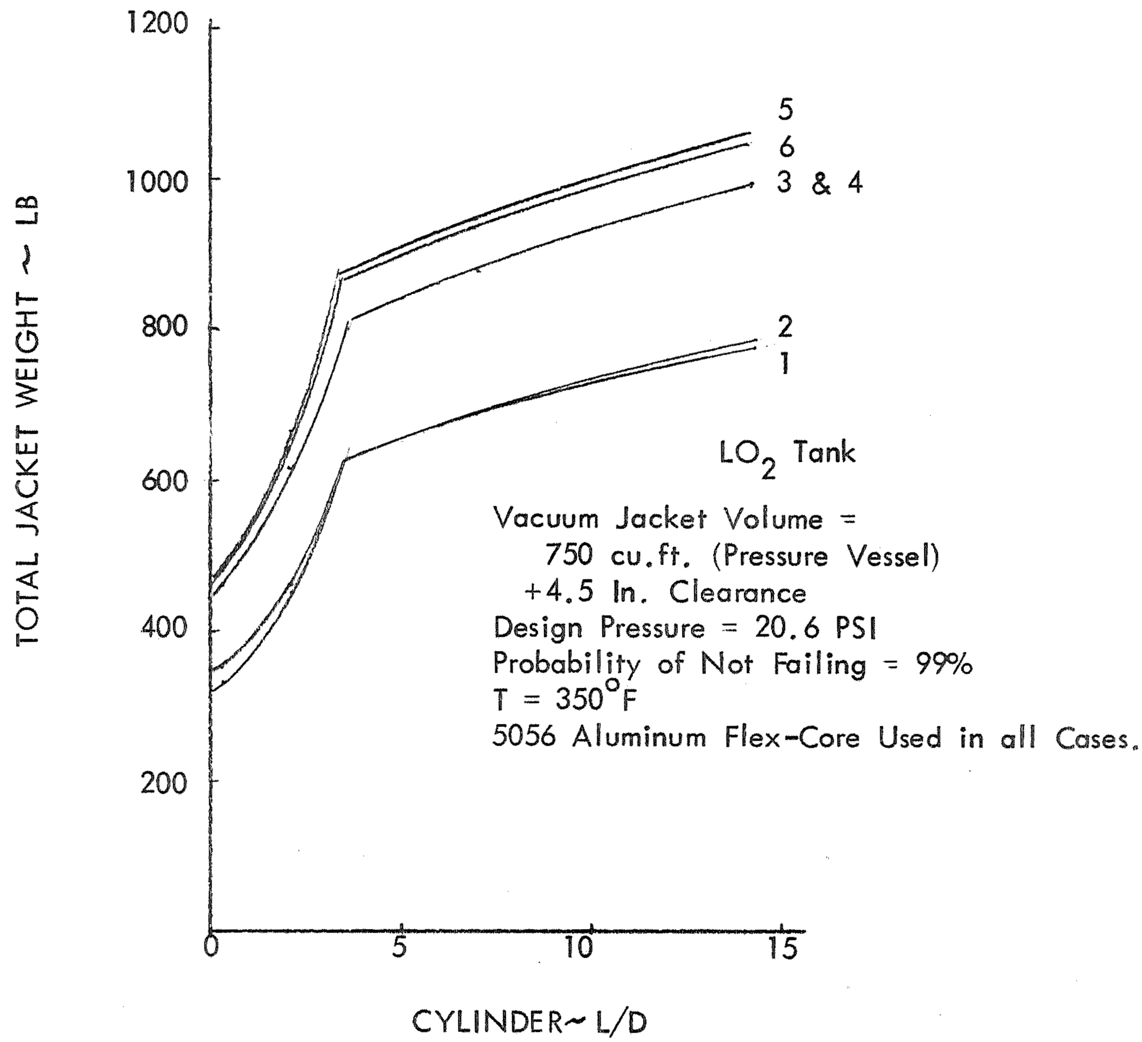


Figure 8: VACUUM JACKET WEIGHTS VS CYLINDER L/D FOR SIX FACE MATERIALS AND 5056 ALUMINUM FLEX-CORE

2.0 TASK II - Vacuum Shell Structural Tests and Vacuum Acquisition Tests

2.1 Material Outgassing Tests

A. Thermogravimetric Analysis (TGA in Helium)

A dynamic TGA in helium from room temperature to 1000°F was run on nine representative material samples. The percentage loss in weight vs. temperature °F is plotted in Figures 9 through 17. Results from these tests are:

1) Glass/epoxy prepreg per BMS 8-139 had no detectable weight loss up to approximately 500°F.

2) Glass/phenolic prepreg per BMS 8-129A shows no weight loss up to 155°F. Weight loss at 350°F is 0.3%.

3) Glass/polyimide prepreg per BMS 8-144 shows a 0.3% weight loss at 100°F, which increases to 1.6% weight loss at 350°F.

4) Boron/epoxy prepreg (Narmco 5505/14) shows an unexplainable weight increase between 120°F and 560°F.

5) Fiberglass/phenolic (HRP) honeycomb core per BMS 8-124E shows a 0.4% weight loss at 110°F which increases to 0.7% weight loss at 350°F.

6) Fiberglass/polyimide (HRH 327E) honeycomb core per BMS 8-125 shows no weight loss up to 140°F. Weight loss at 350°F is 0.2%.

7) 5052 flex-core had no detectable weight loss up to 1000°F. A slight weight increase is shown at 350°F and above which suggests oxidation of aluminum by traces of oxygen.

8) Adhesive BMS 5-17 shows a 0.4% weight loss at 185°F which increases to 0.6% weight loss at 350°F.

9) Adhesive metlbond 325 shows no weight loss up to 170°F. Weight loss at 350°F is 0.2%.

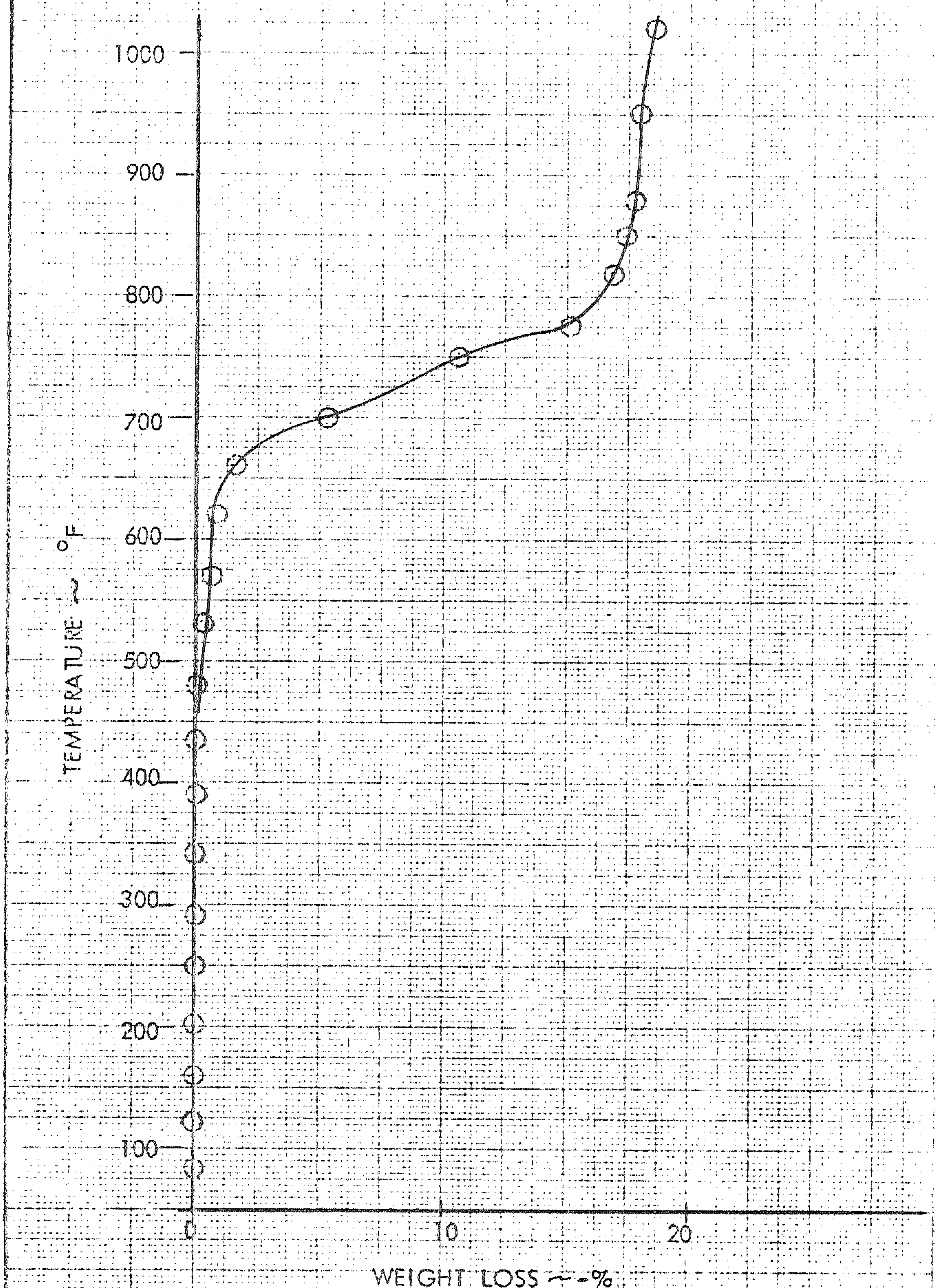


Figure 9: WEIGHT LOSS VS TEMPERATURE (TGA in He) - GLASS/EPOXY PREPREG PER BMS 8-139

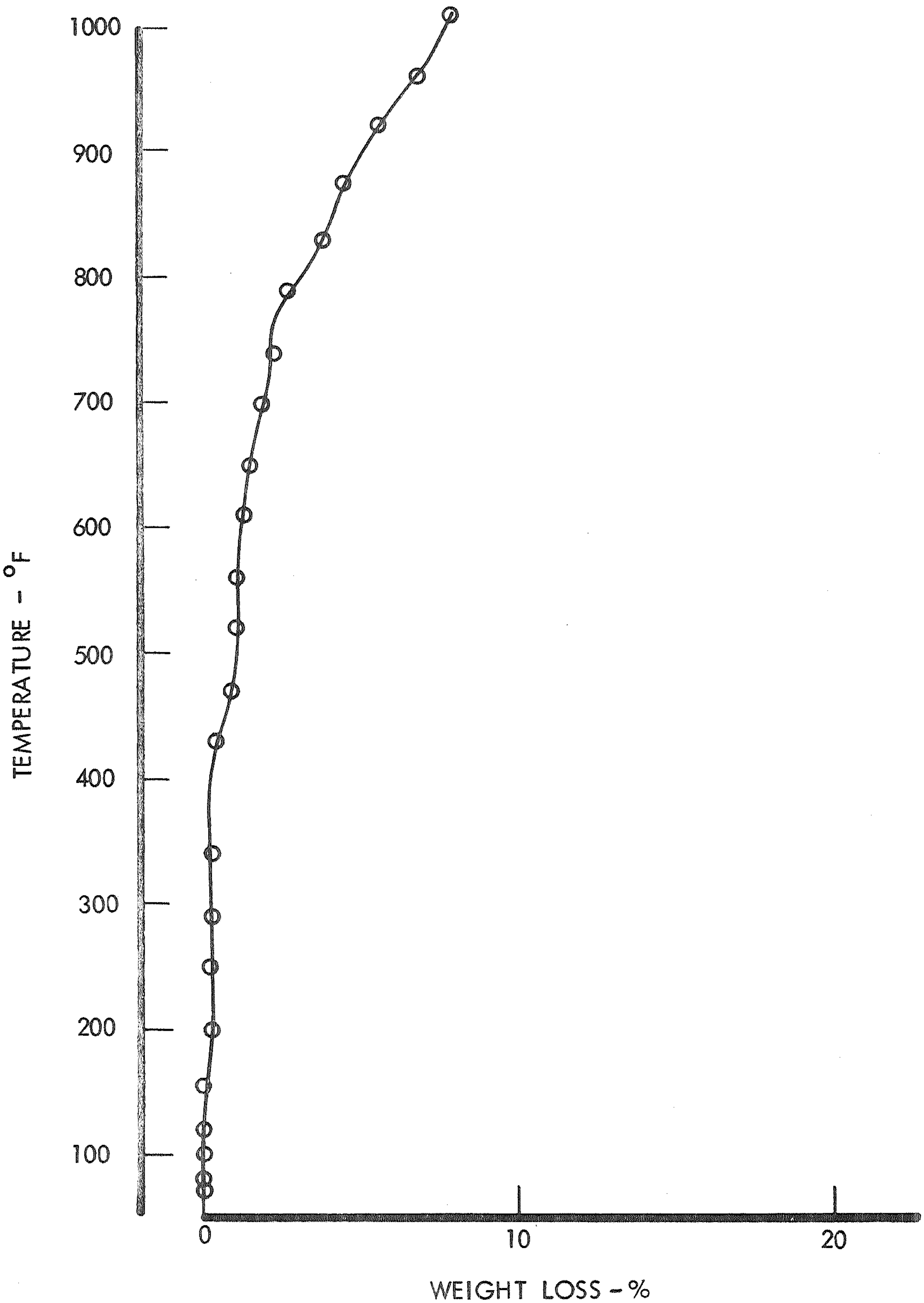


Figure 10 : WEIGHT LOSS VS TEMPERATURE (TGA IN He)
GLASS/PHENOLIC PREPREG PER BMS 8-129A

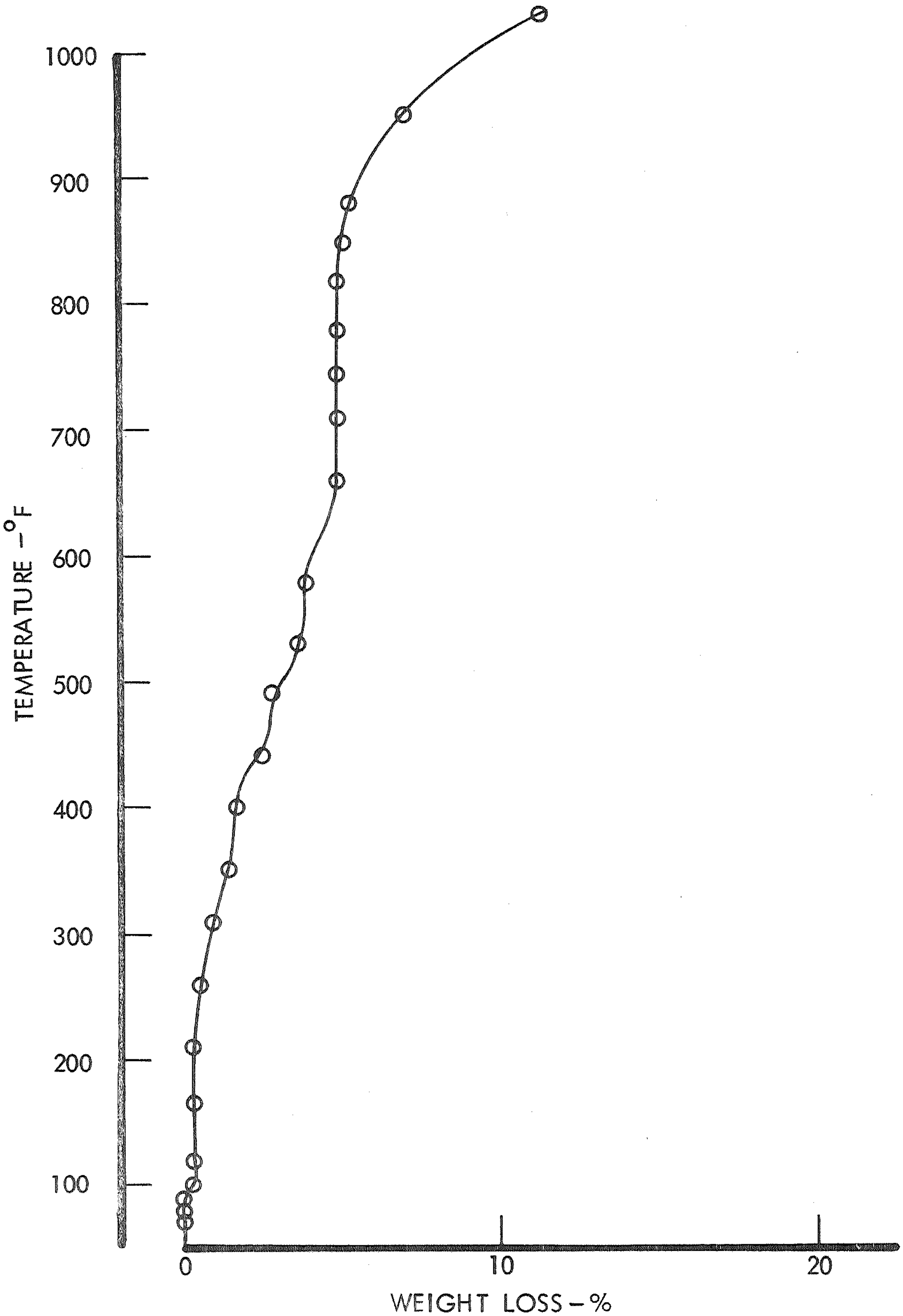


Figure 11 : WEIGHT LOSS VS TEMPERATURE (TGA IN He)
GLASS/POLYIMIDE PREPREG PER BMS 8-144

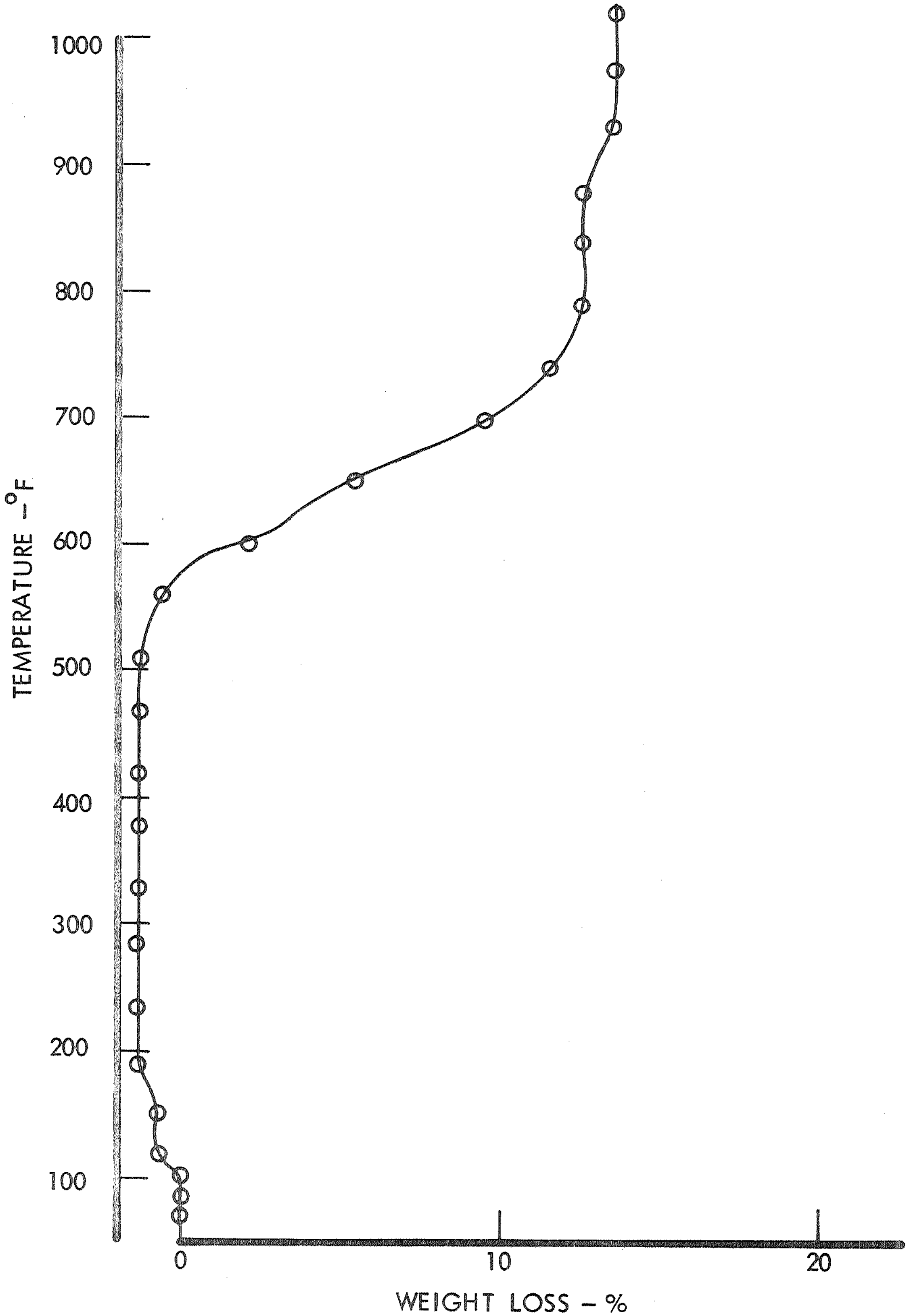


Figure 12 : WEIGHT LOSS VS TEMPERATURE (TGA IN He)
BORON EPOXY PREPREG (NARMCO 5505/14)

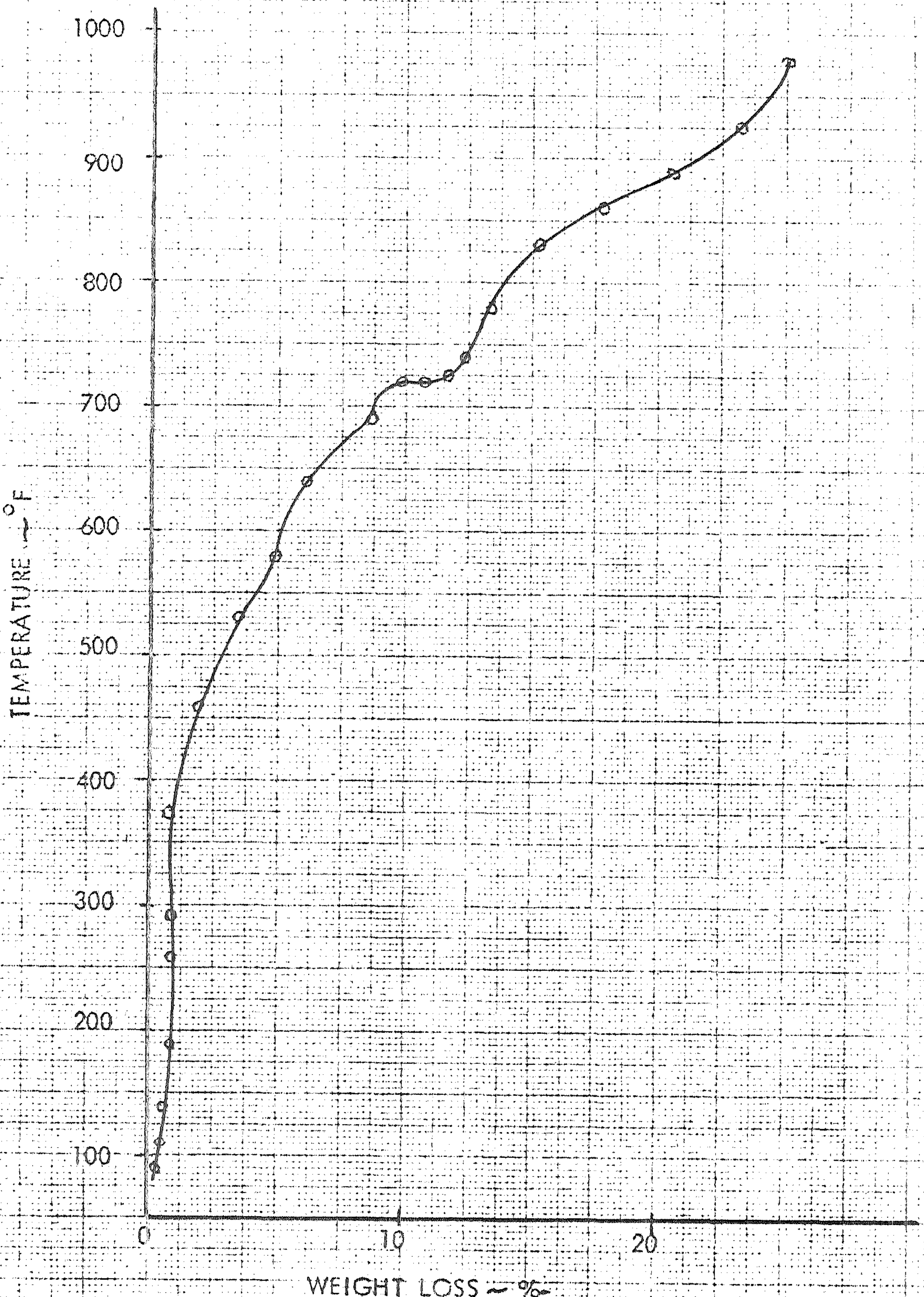


Figure 13 WEIGHT LOSS VS TEMPERATURE (TGA in He) - FIBERGLASS/PHENOLIC (HRP) HONEYCOMB CORE PER BMS 8-124E

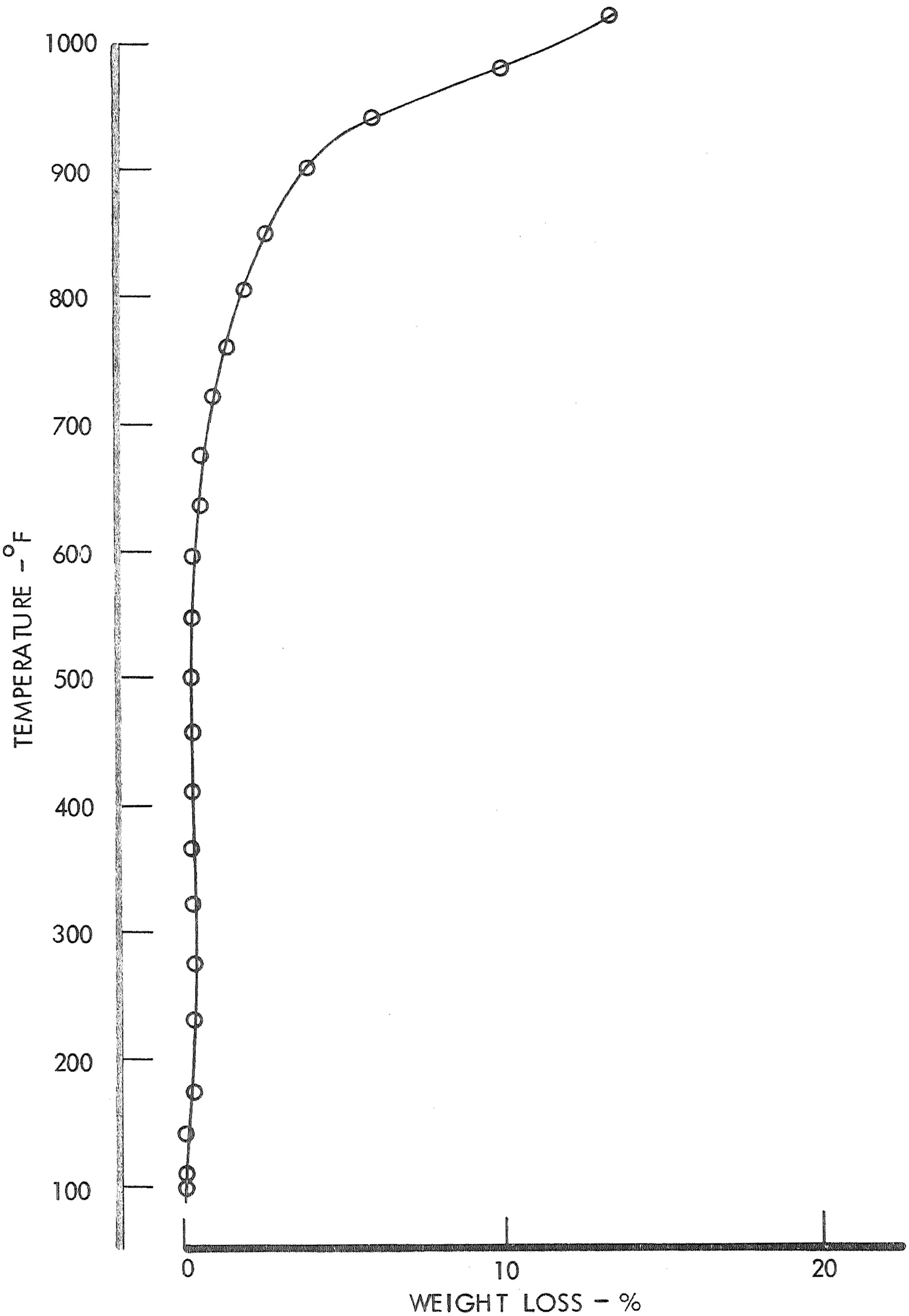


Figure 14 : WEIGHT LOSS VS TEMPERATURE (TGA IN He)
FIBERGLASS/POLYIMIDE (HRH 327E)
HONEYCOMB CORE PER BMS 8-125

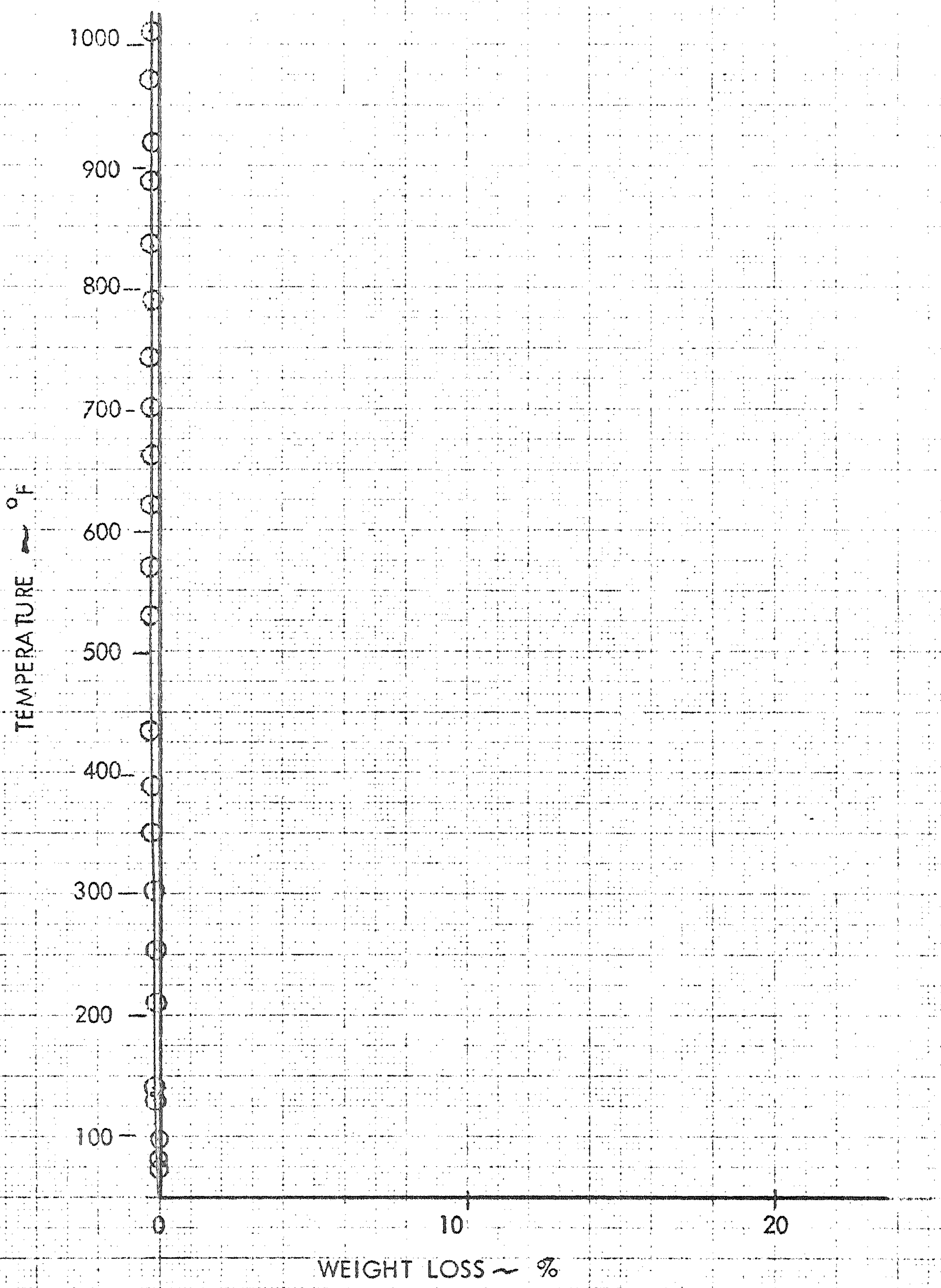


Figure 15: WEIGHT LOSS VS TEMPERATURE (TGA in He) - 5052 ALUMINUM FLEX-CORE

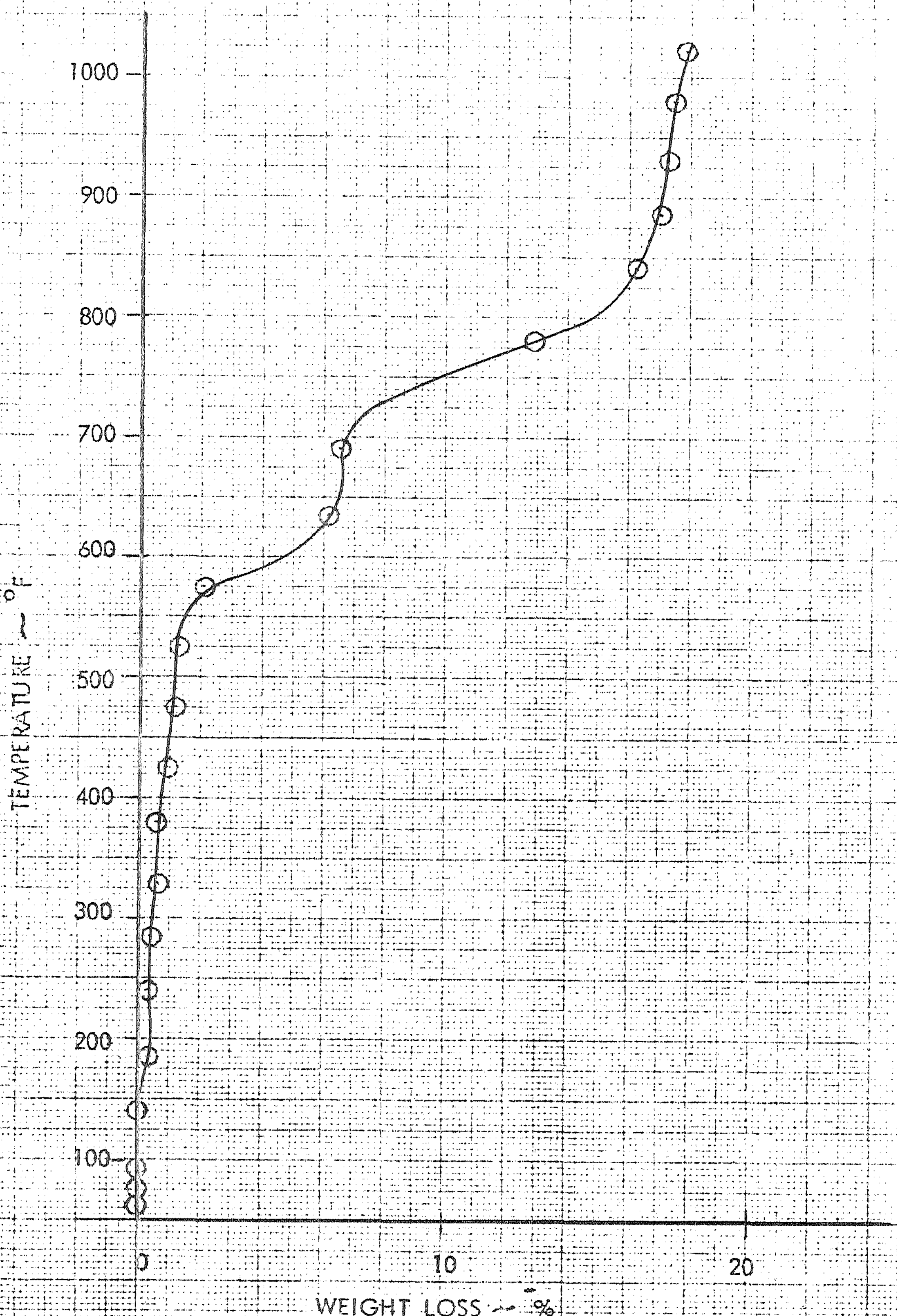


Figure 16: WEIGHT VS TEMPERATURE (TGA in He) - EPOXY ADHESIVE PER BMS 5-17

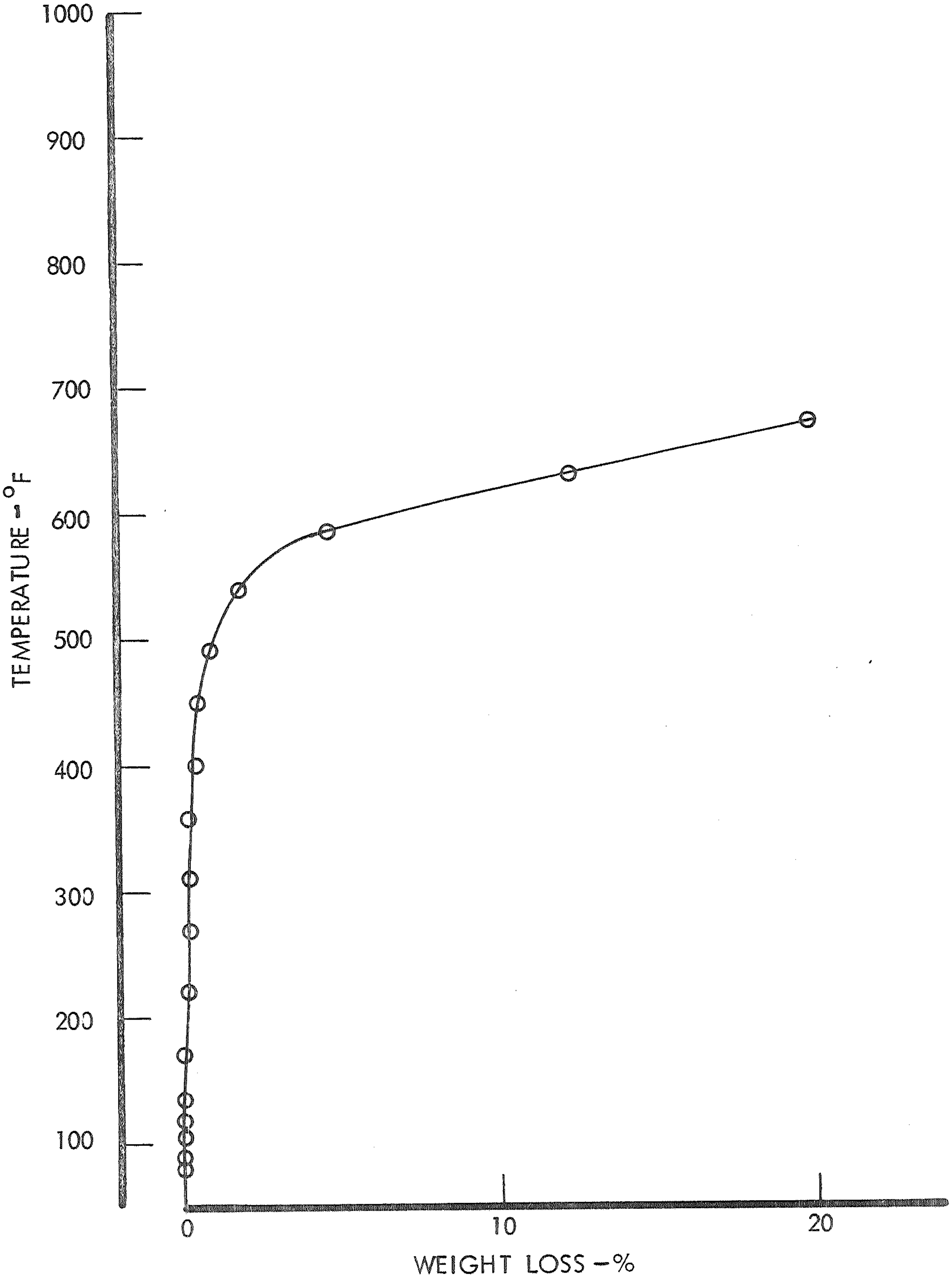


Figure 17: WEIGHT LOSS VS TEMPERATURE (TGA IN He)
METLBOND 329 ADHESIVE

B. Differential Thermal Analysis (DTA)

A DTA in nitrogen was run on nine representative material samples. The heat reaction vs. temperature results are plotted in Figure 18 through 26.

The DTA results are in accord and confirm the TGA and the isotherm TGA results.

C. Isotherm TGA

An isotherm TGA in a vacuum at 350°F was run on nine representative material samples. The percentage of original weight vs. time at 350°F in a vacuum is plotted in Figures 27 through 35. Results from these tests are:

1) Glass/epoxy prepreg per BMS 8-139 shows 97.7% of original weight after 270 minutes.

2) Glass/phenolic prepreg per BMS 8-129A shows 97.7% of original weight after 310 minutes.

3) Glass/polyimide prepreg per BMS 8-144 shows 96.0% of original weight after 270 minutes.

4) Boron/epoxy prepreg (Narmco 5505/14) shows 99.4% of original weight after 260 minutes.

5) Fiberglass/phenolic (HRP) honeycomb core per BMS 8-124E shows 96.7% of the original weight after 320 minutes.

6) Fiberglass/polyimide (HRH 327E) honeycomb core per BMS 8-125 shows 98.2% of the original weight after 280 minutes.

7) 5052 aluminum flex-core shows 99.7% of the original weight after 320 minutes.

8) Epoxy adhesive per BMS 5-17 shows 97.2% of original weight after 290 minutes.

9) Metlbond 329 adhesive shows 97.7% of the original weight after 320 minutes.

FIGURE 18: DIFFERENTIAL THERMAL ANALYSIS (DTA)
GLASS/EPOXY PREPREG PER BMS 8-139

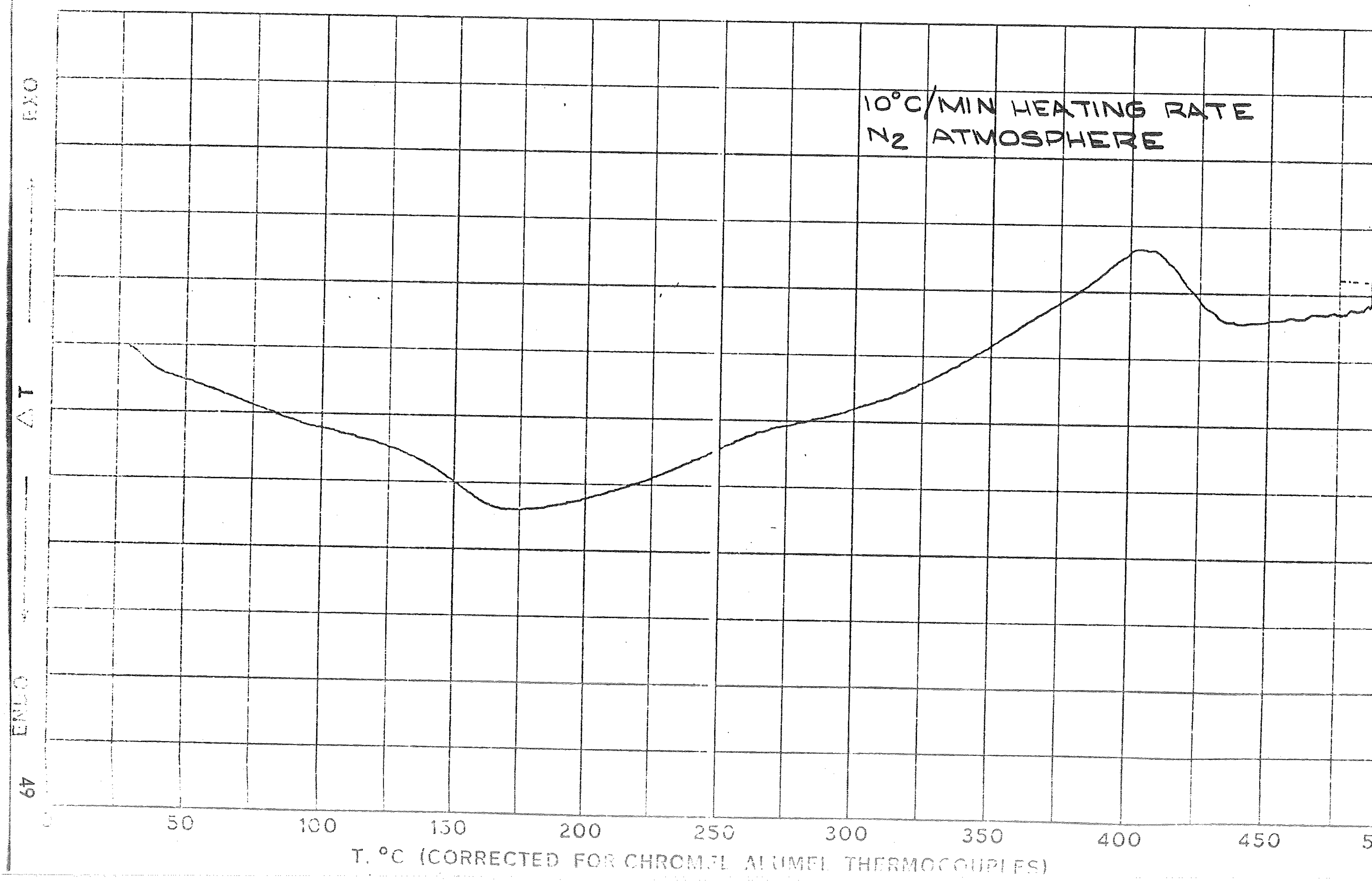


FIGURE 19: DIFFERENTIAL THERMAL ANALYSIS (DTA)
GLASS/PHENOLIC PREPREG PER BMS 8-129A

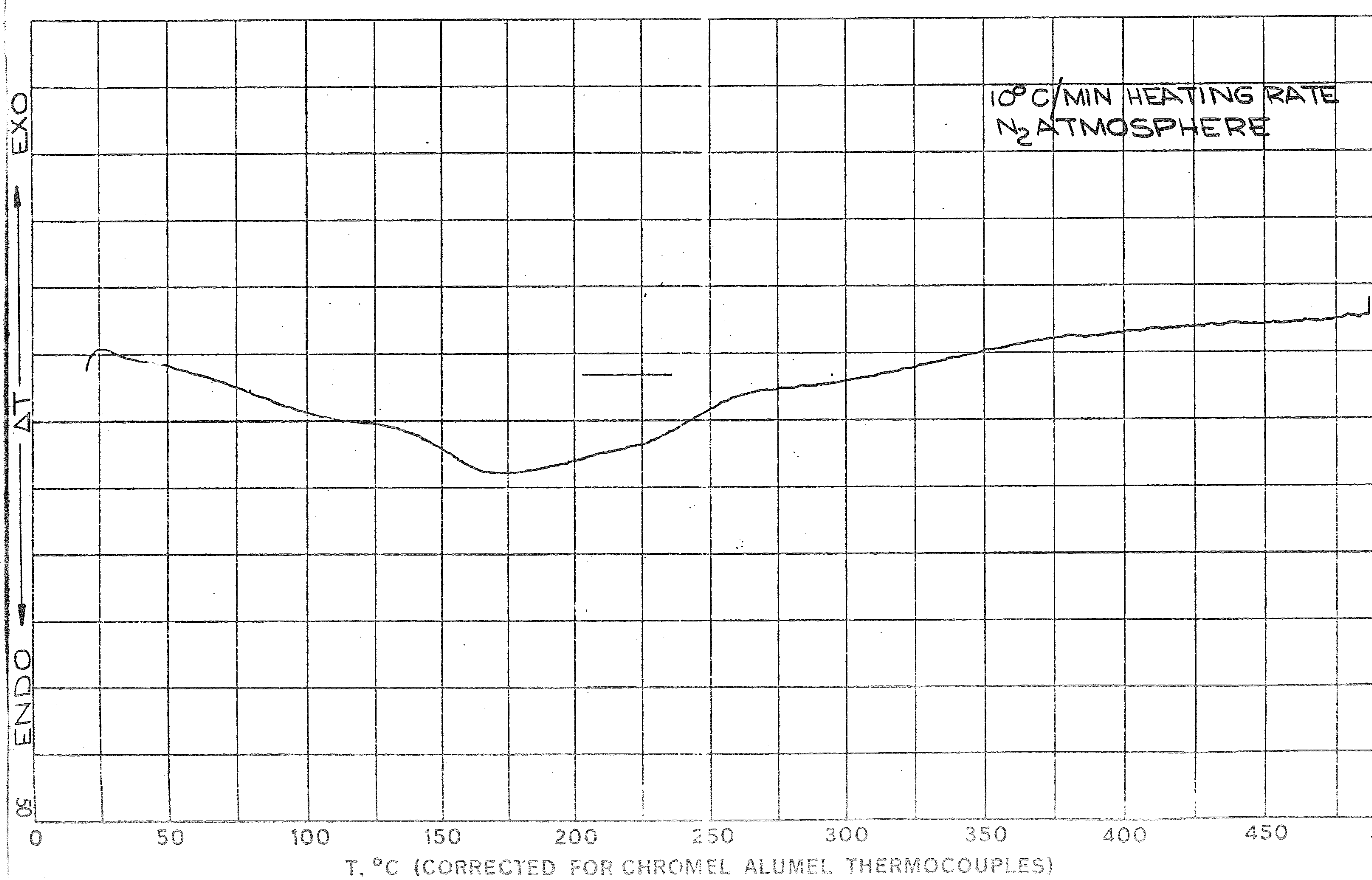


FIGURE 20: DIFFERENTIAL THERMAL ANALYSIS (DTA)
GLASS/POLYIMIDE PREPREG PER BMS 8-144

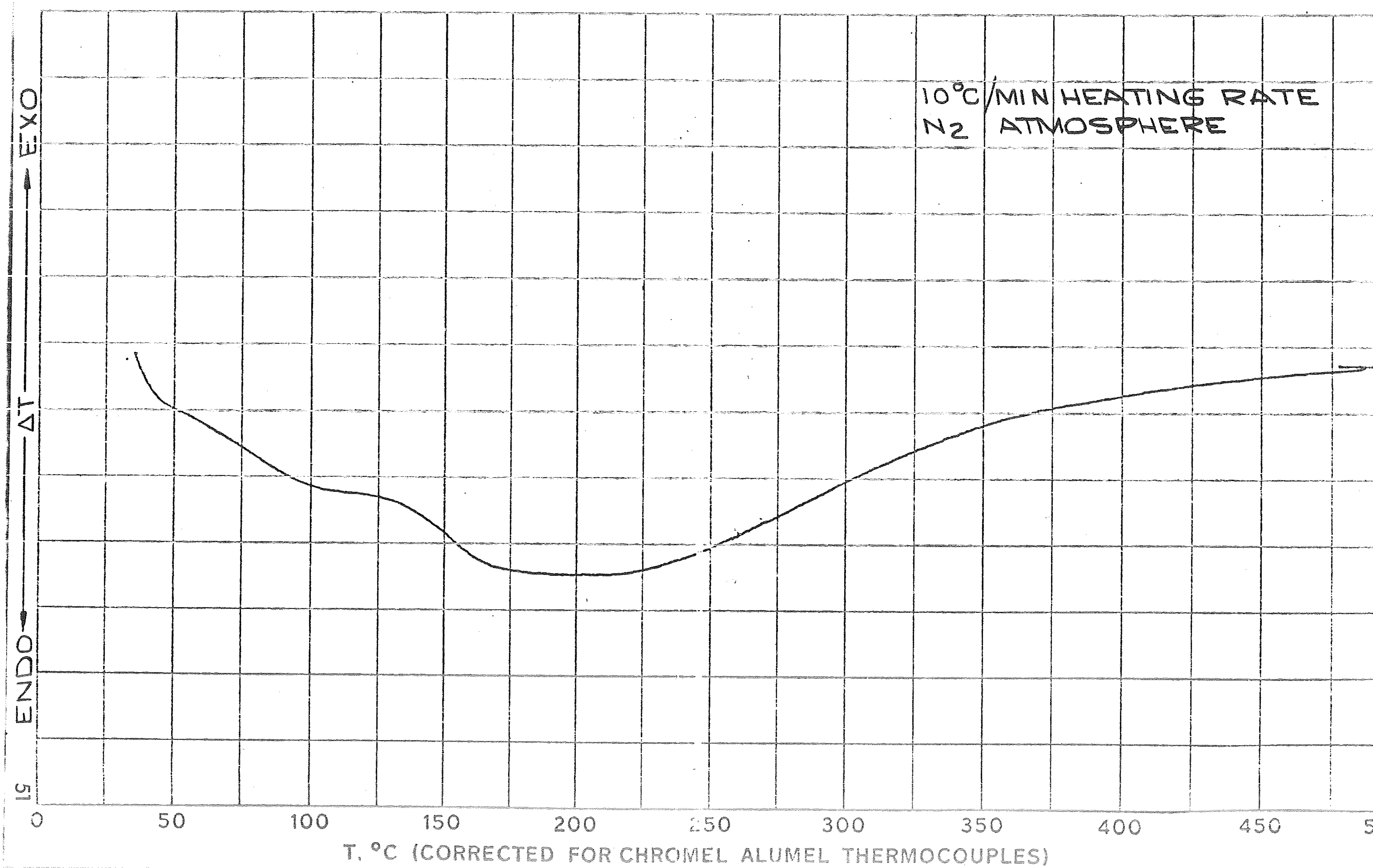


FIGURE 21: DIFFERENTIAL THERMAL ANALYSIS (DTA) BORON/EPOXY PREPREG (NARMCO (5504/14)

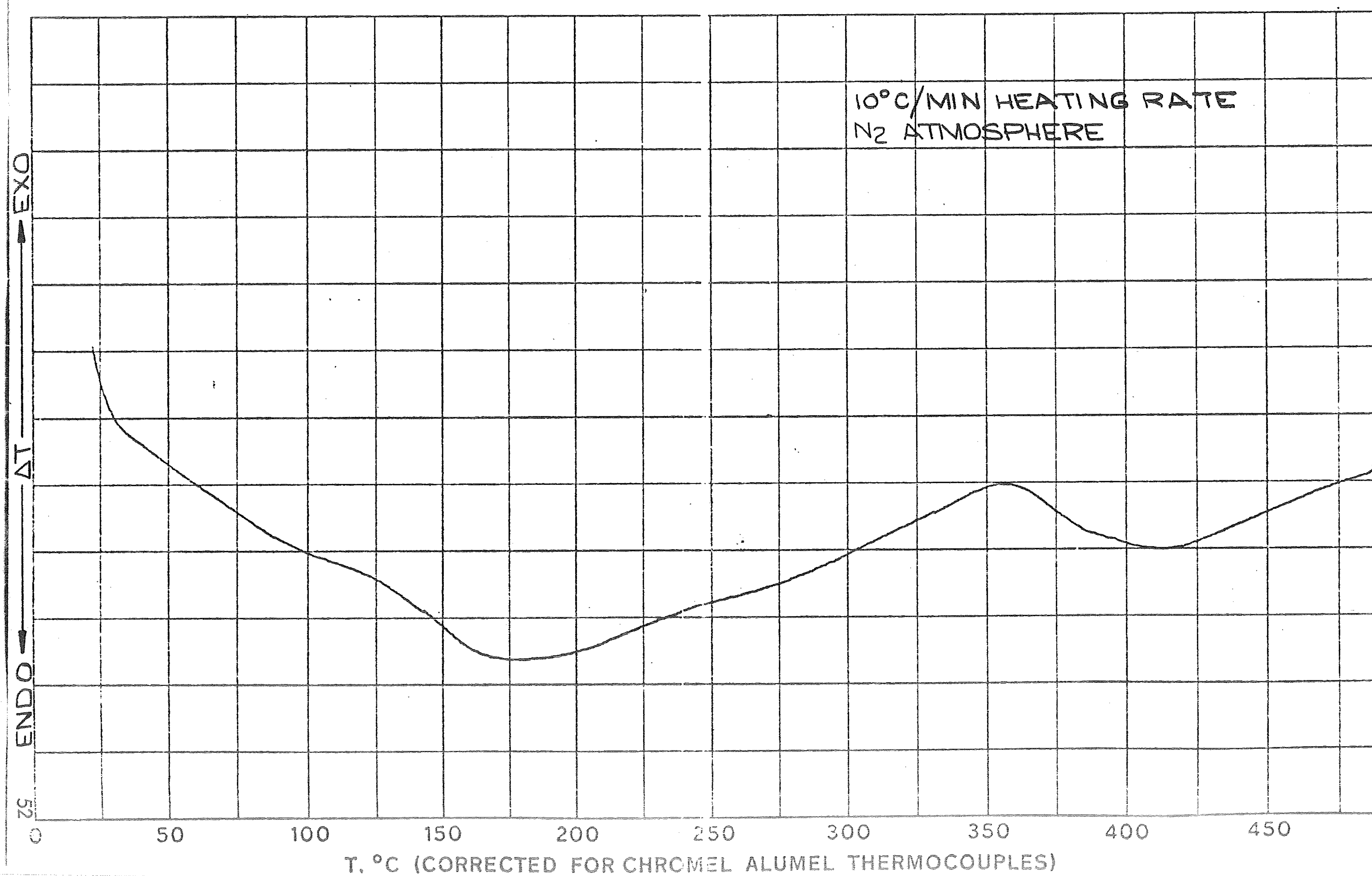


FIGURE 22: DIFFERENTIAL THERMAL ANALYSIS (DTA)
FIBERGLASS/PHENOLIC (HRP)
HONEYCOMB CORE PER BMS 8-124E

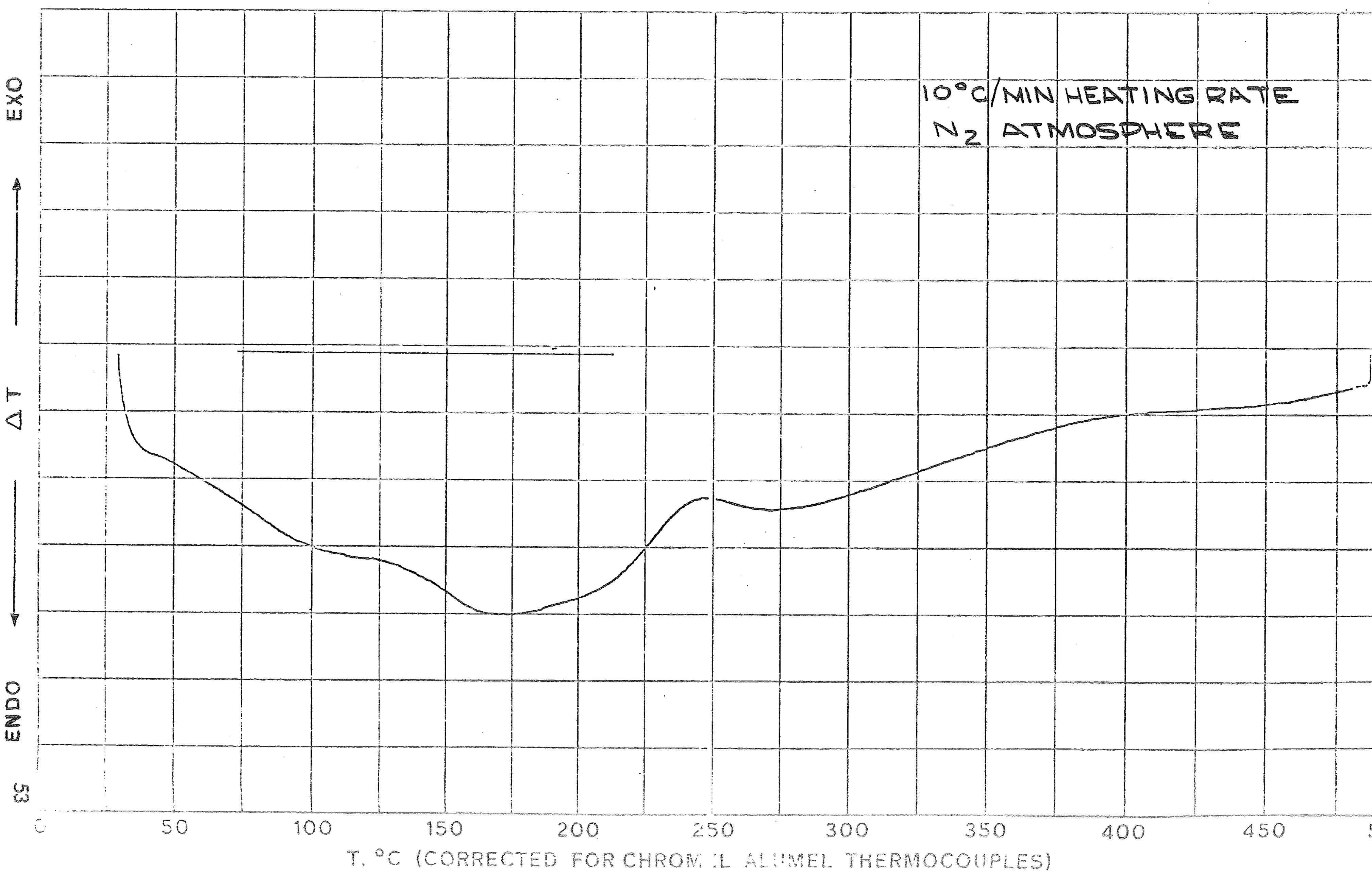


FIGURE 23 : DIFFERENTIAL THERMAL ANALYSIS (DTA)
FIBERGLASS/POLYIMIDE (HRH 327E)
HONEYCOMB CORE PER BMS 8-125

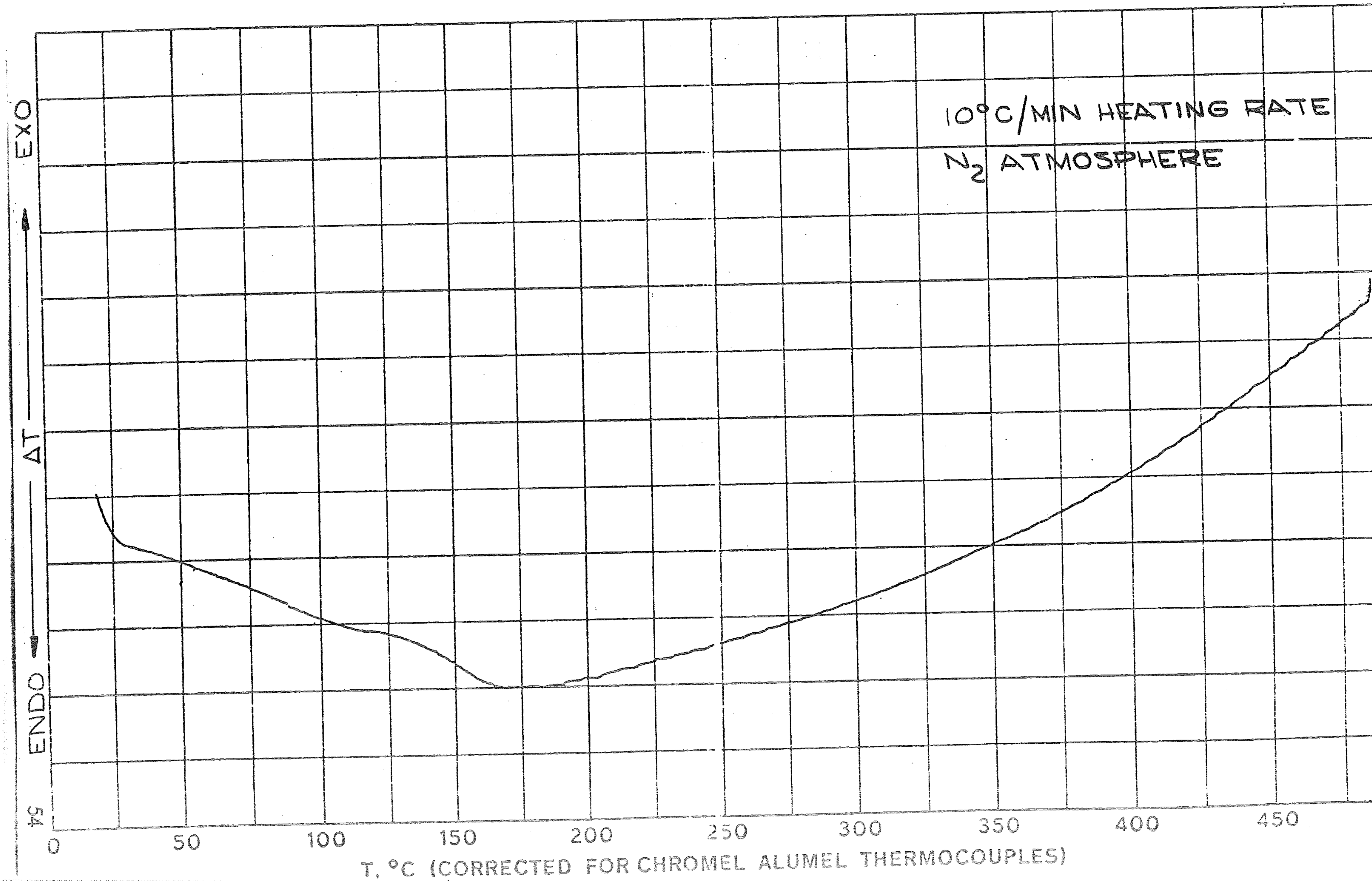


FIGURE 24: DIFFERENTIAL THERMAL ANALYSIS (DTA)
5052 ALUMINUM FLEXCORE

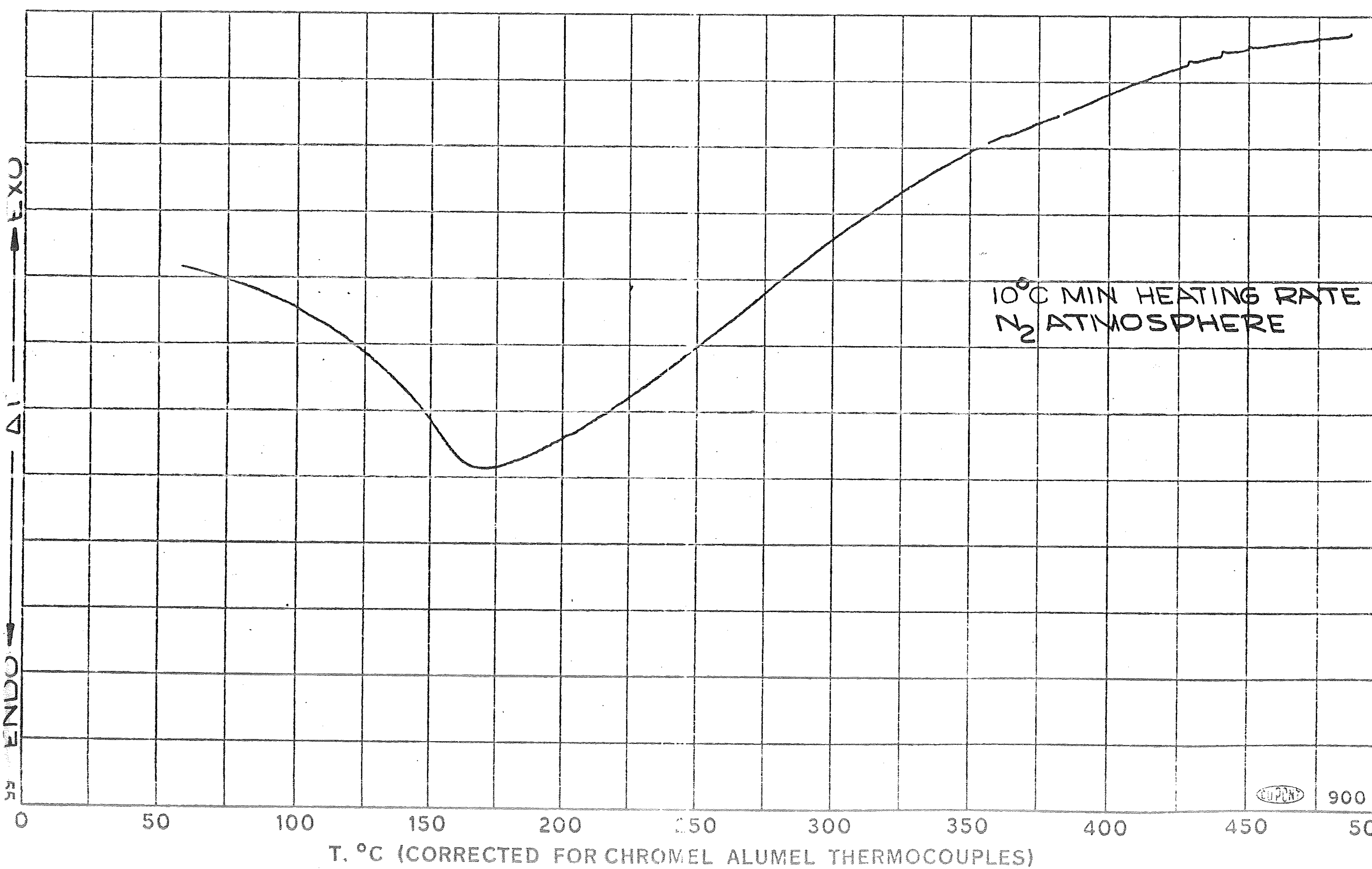


FIGURE 25: DIFFERENTIAL THERMAL ANALYSIS (DTA)
EPOXY ADHESIVE PER BMS 5-17

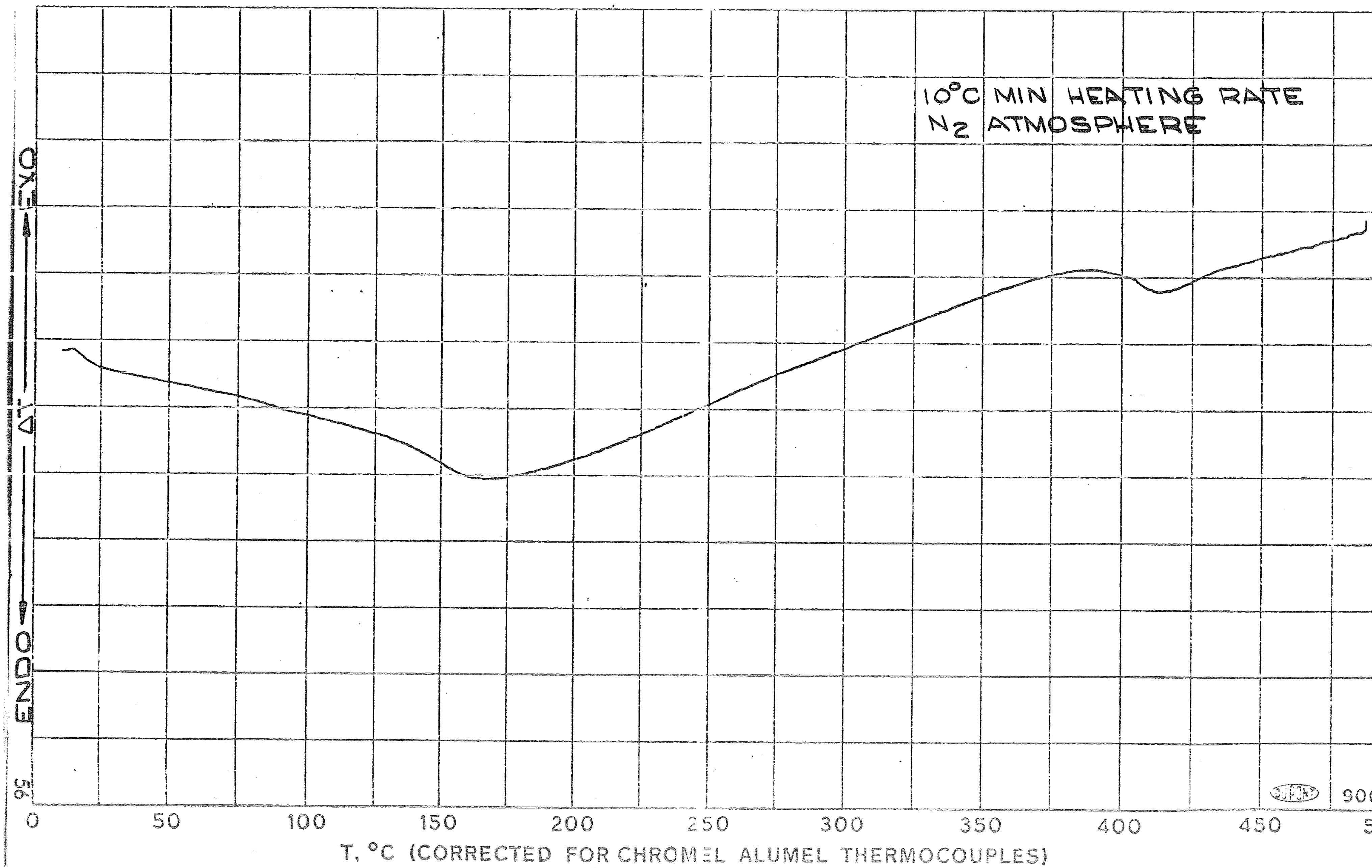


FIGURE 26: DIFFERENTIAL THERMAL ANALYSIS (DTA)
METLBOND 329 ADHESIVE

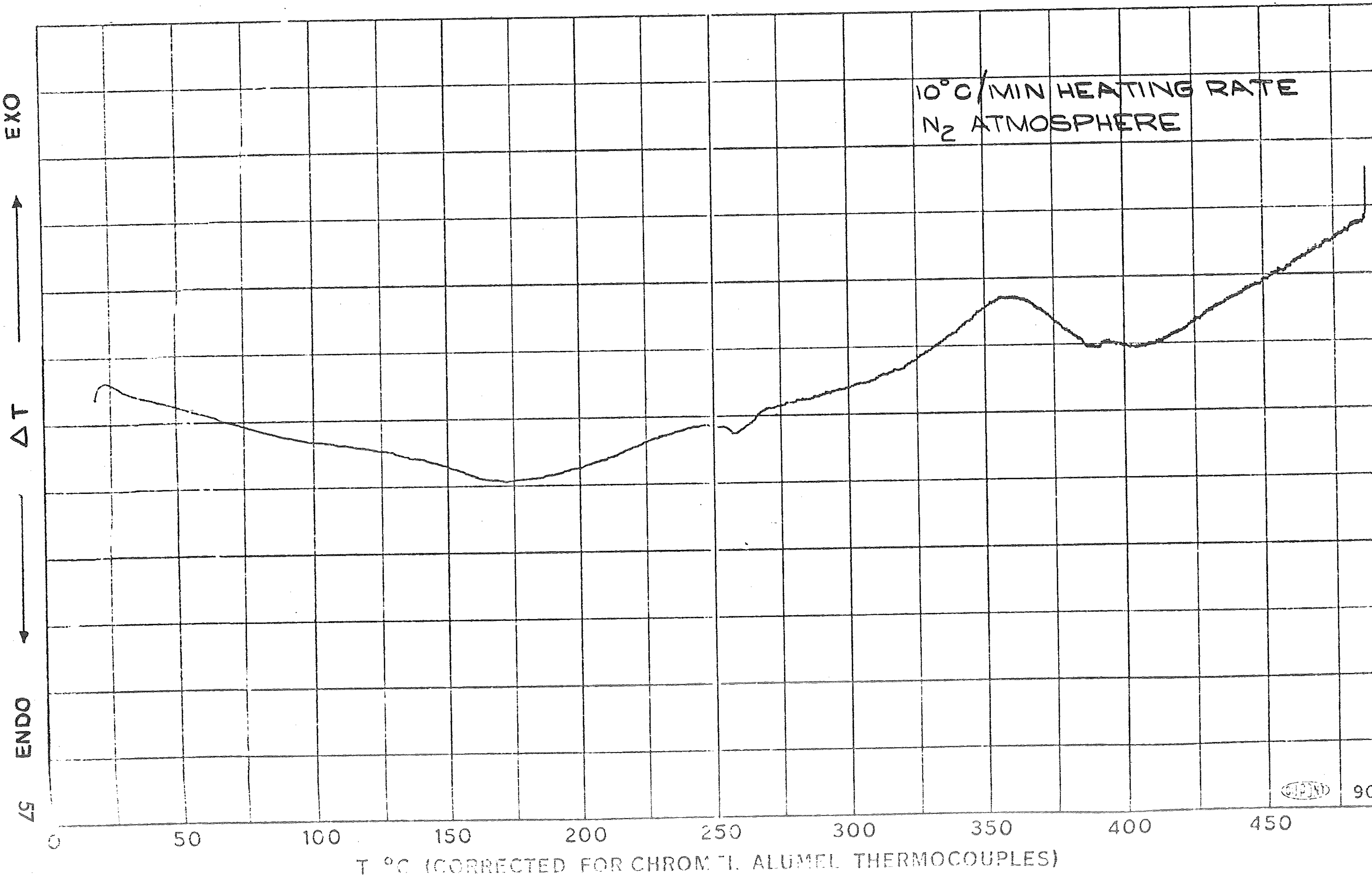
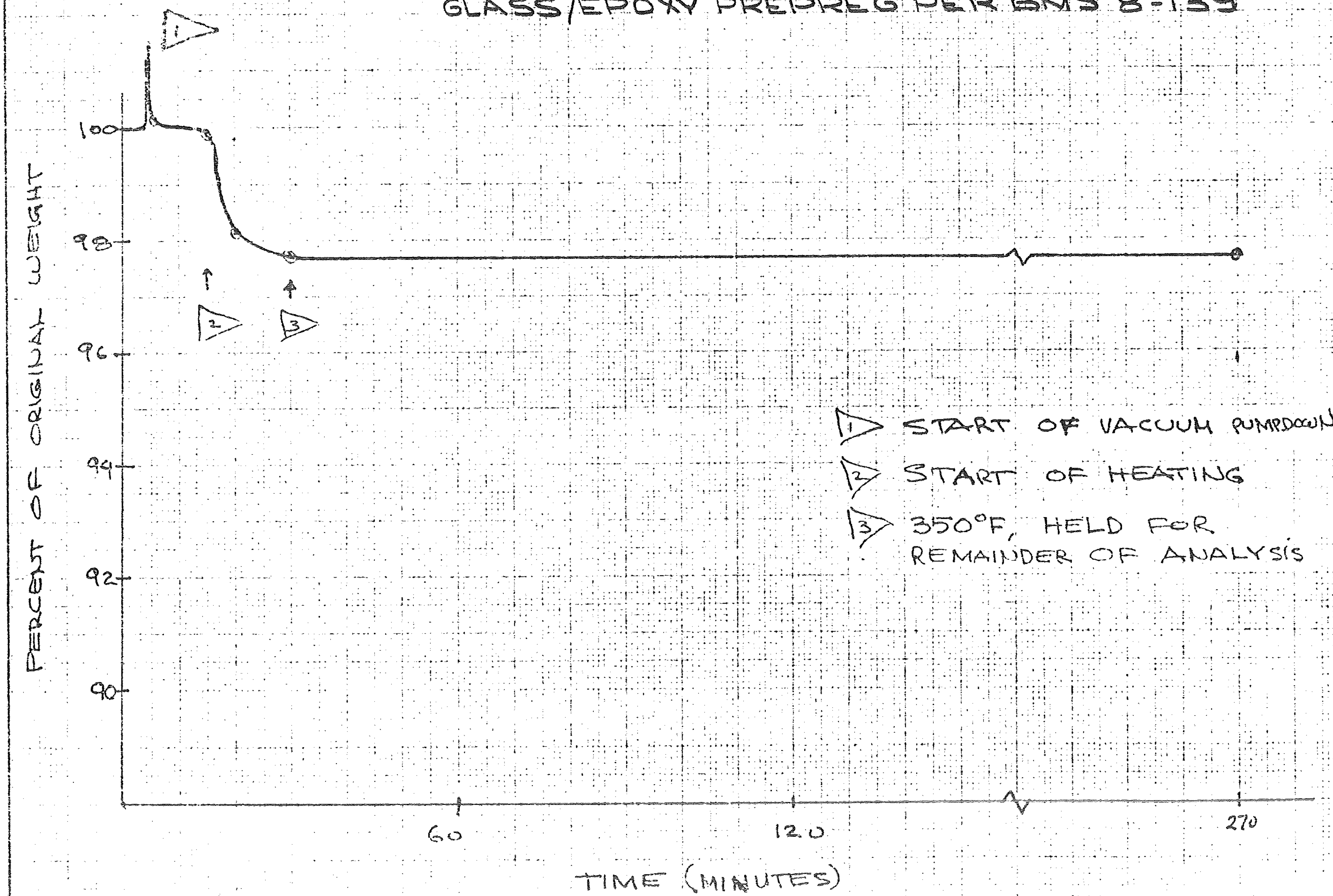


FIGURE 27: ISOTHERMAL GRAVIMETRIC ANALYSIS
(350° F IN VACUUM)
GLASS/EPOXY PREPREG PER BMS 8-139



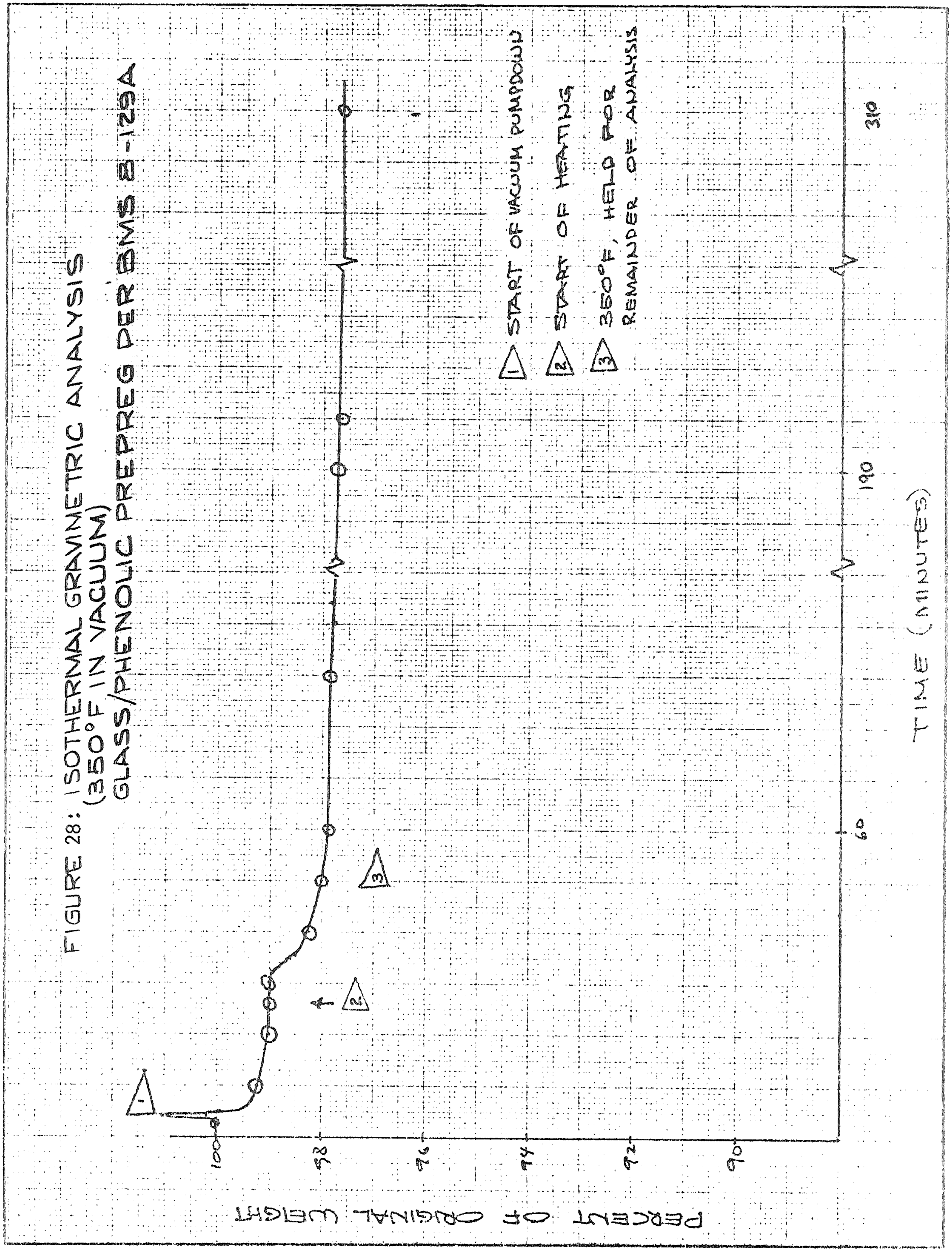
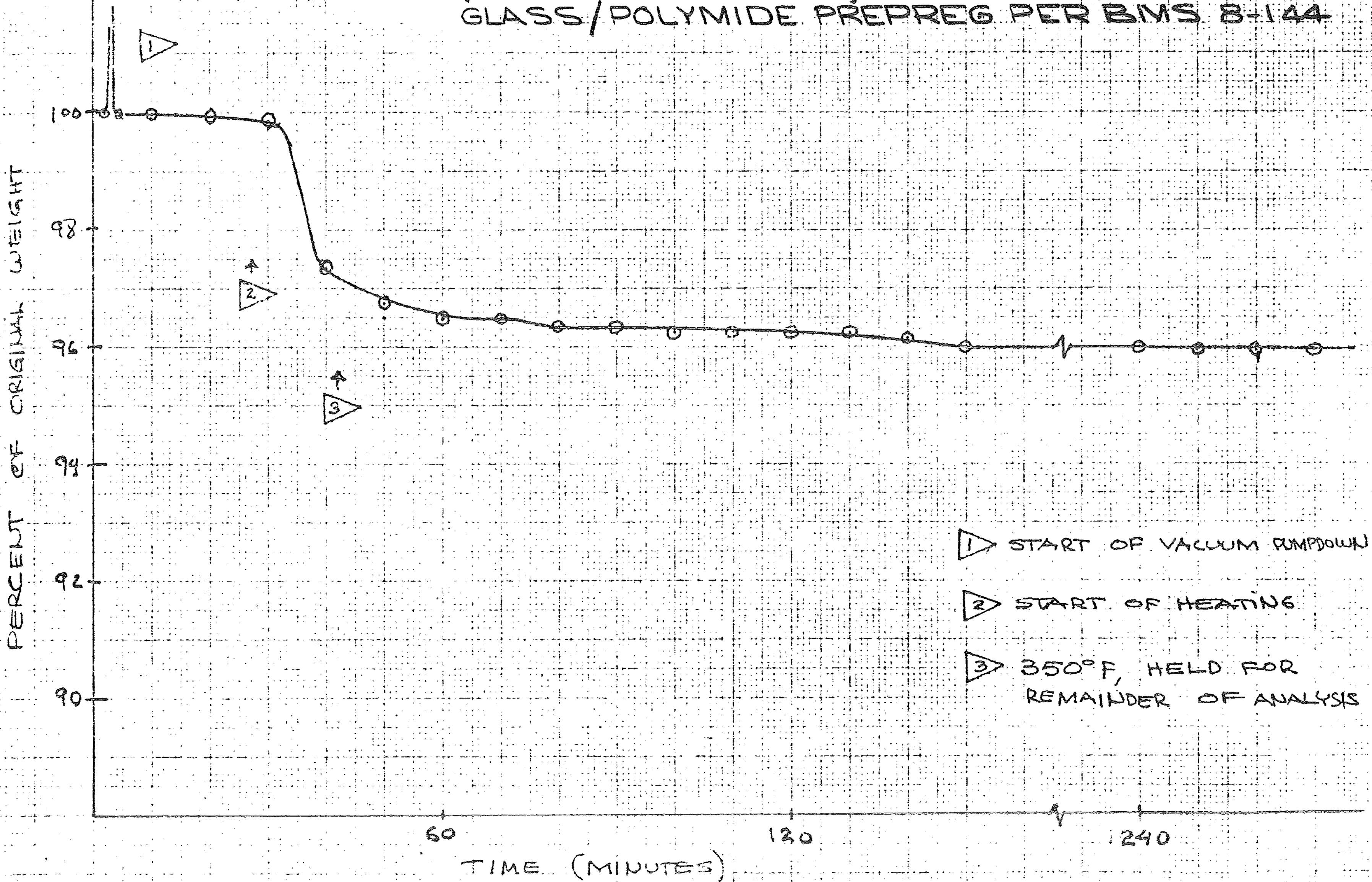


FIGURE 28: ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM) GLASS/PHENOLIC PREPREG PER BMS 8-129A

FIGURE 29: ISOTHERMAL GRAVIMETRIC ANALYSIS
(350° F IN VACUUM)
GLASS/POLYMIDE PREPREG PER BMS 8-144



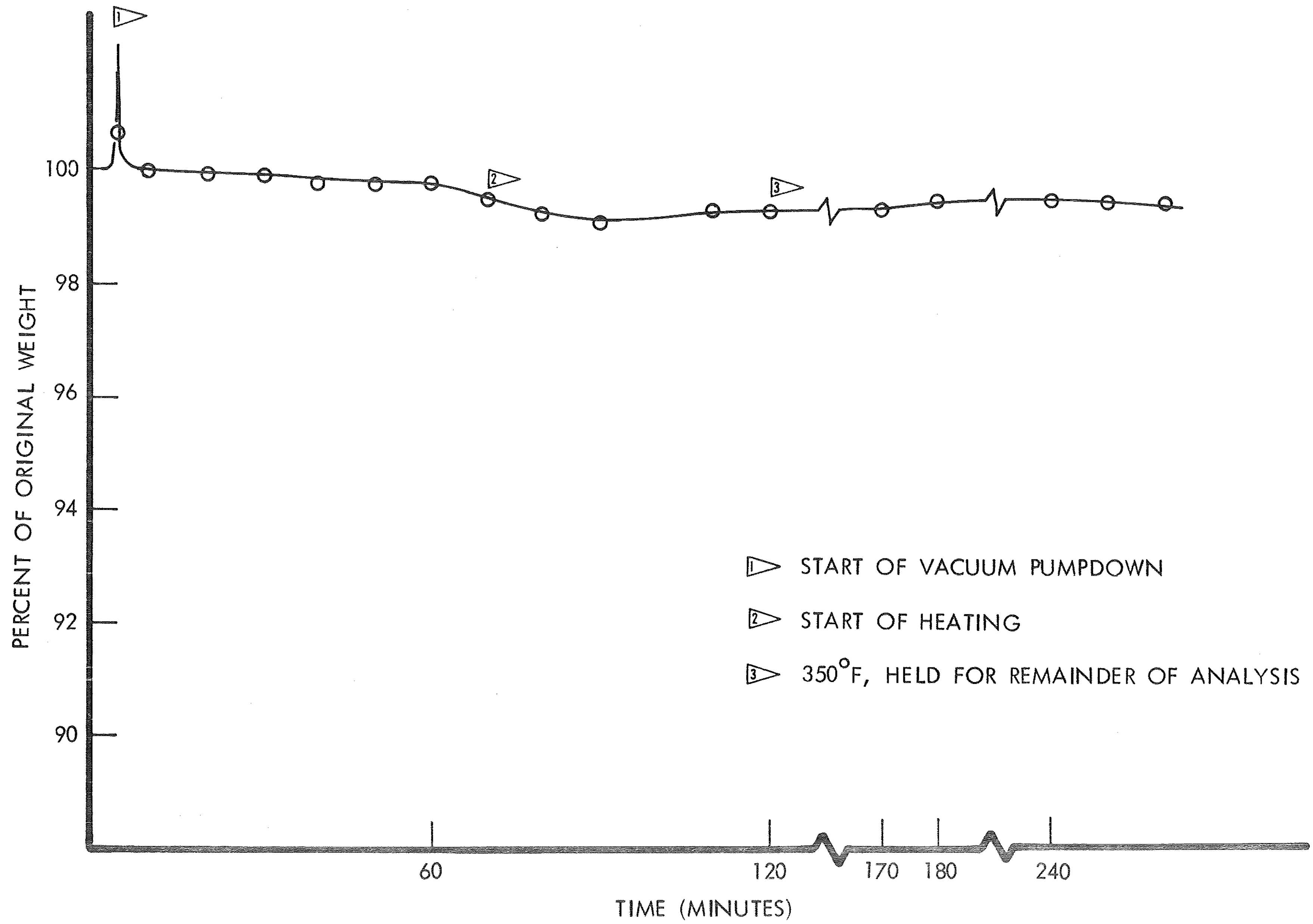


Figure 30: ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM)
BORON/EPOXY PREPREG (NARMCO 5505/14)

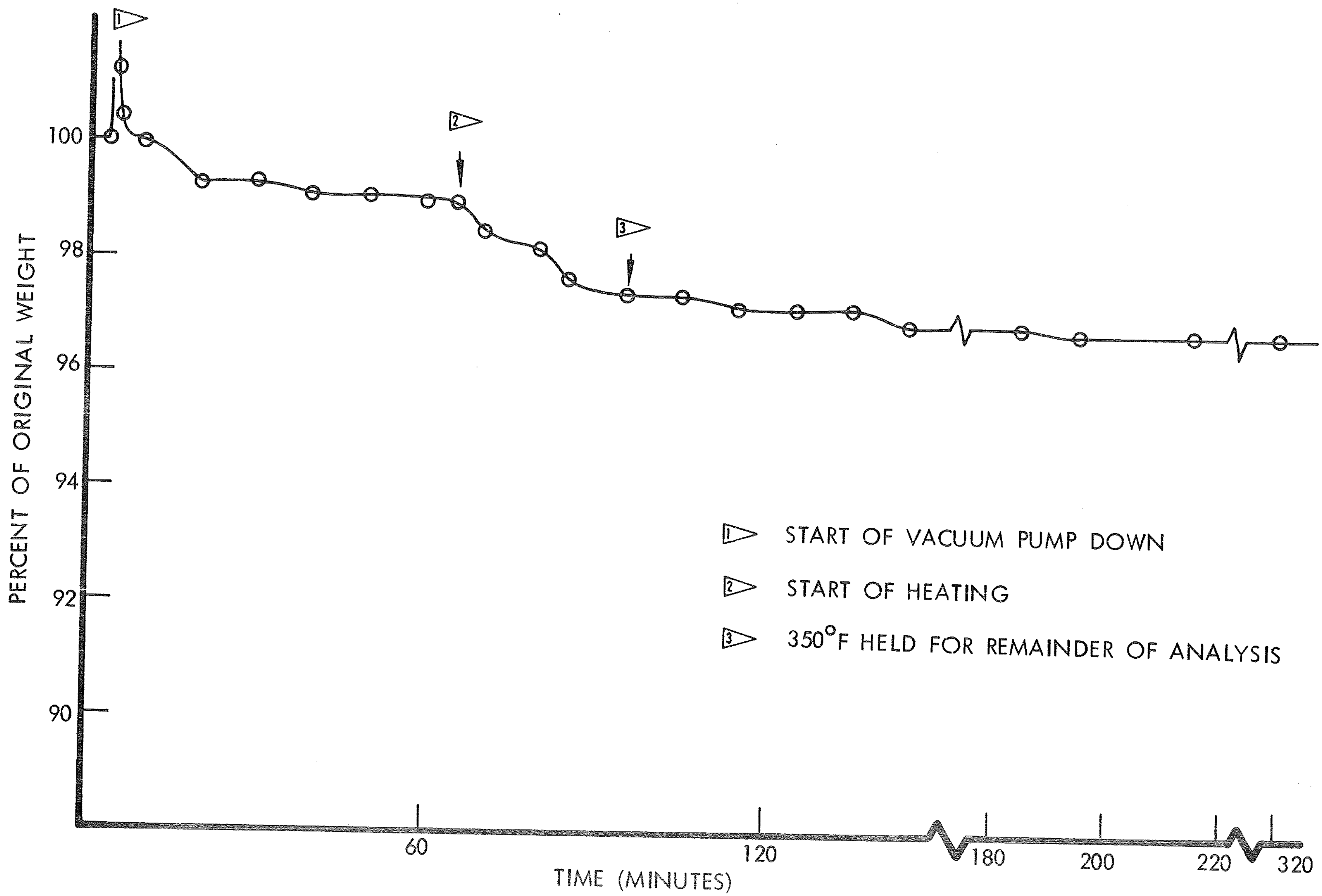


Figure 31: ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM)
FIBERGLASS/PHENOLIC (HRP) HONEYCOMB CORE PER BMS 8-124E

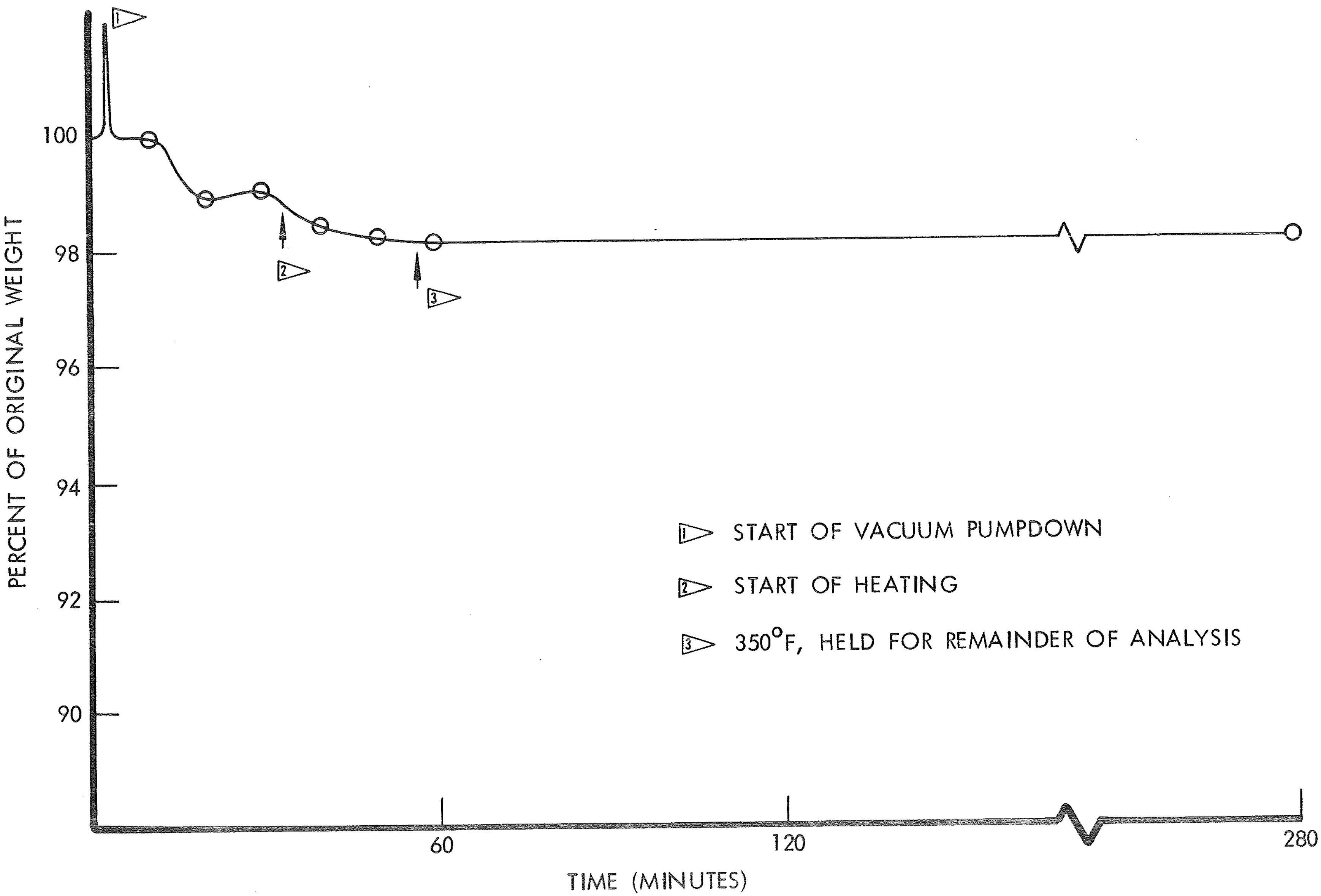


Figure 32: ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM)
FIBERGLASS/POLYMIDE (HRH 327E) HONEYCOMB CORE PER BMS 8-125

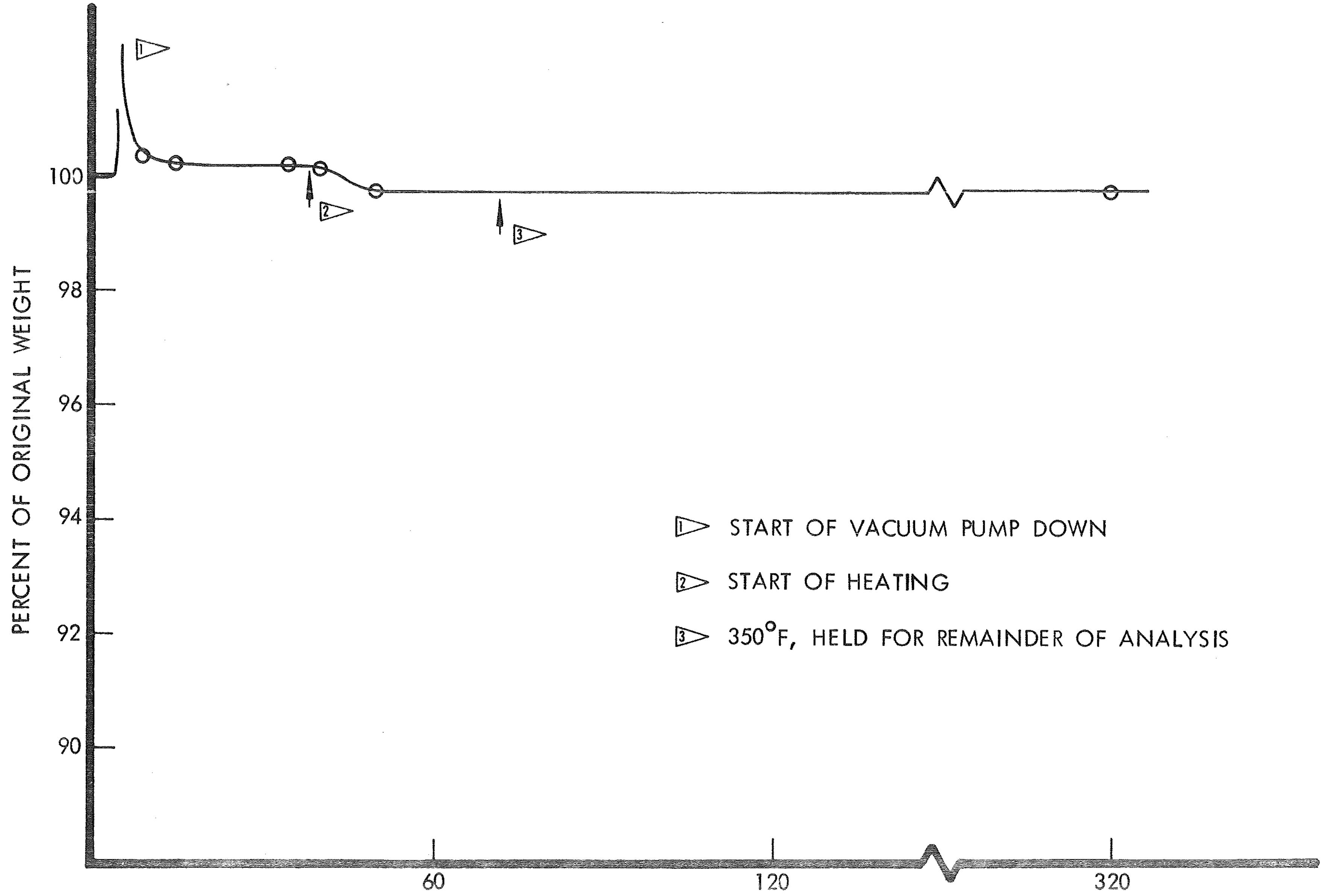


Figure 33 : ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM)
5052 ALUMINUM FLEX-CORE (.0013)

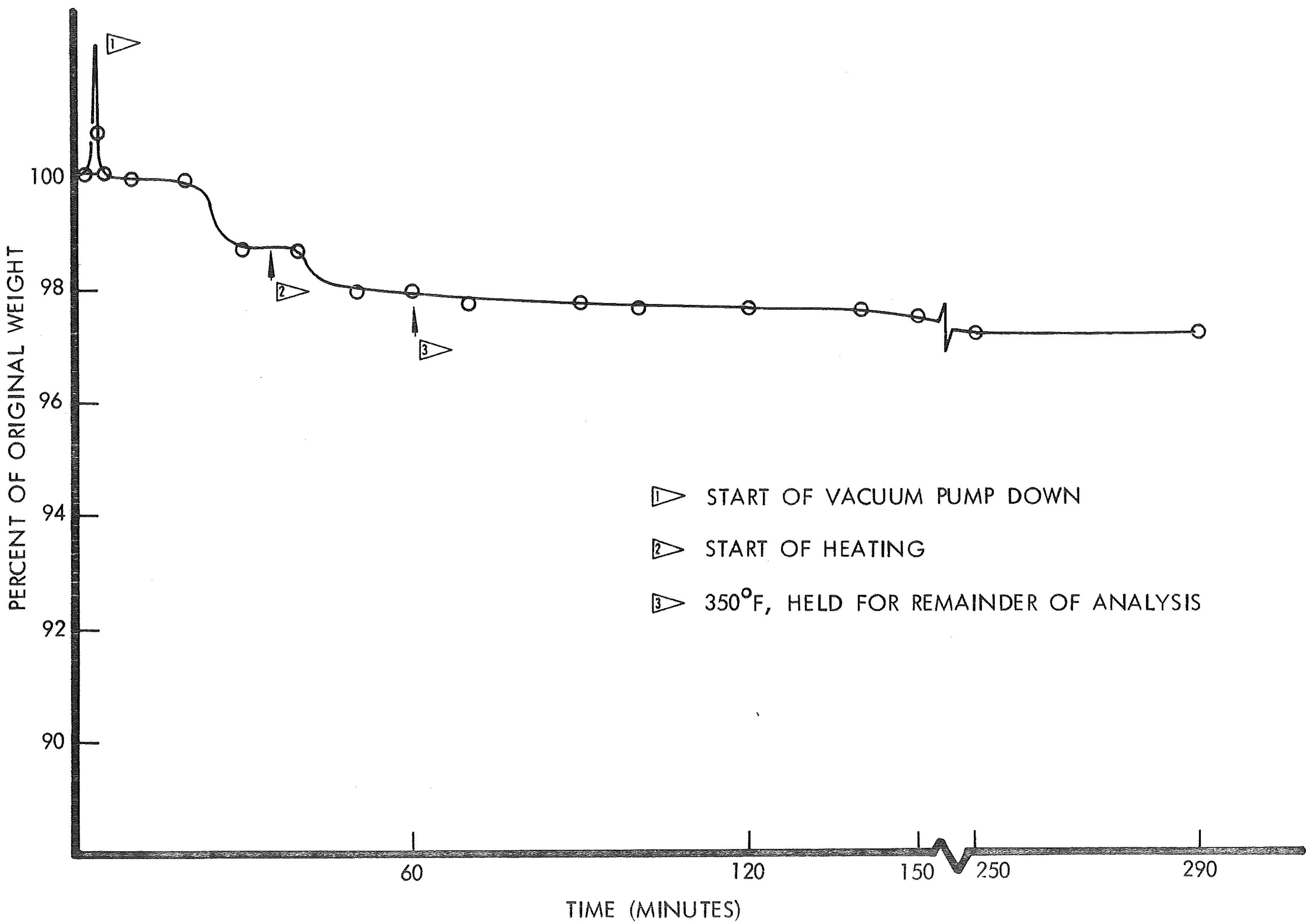


Figure 34 : ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM)
EPOXY ADHESIVE PER BMS 5-17

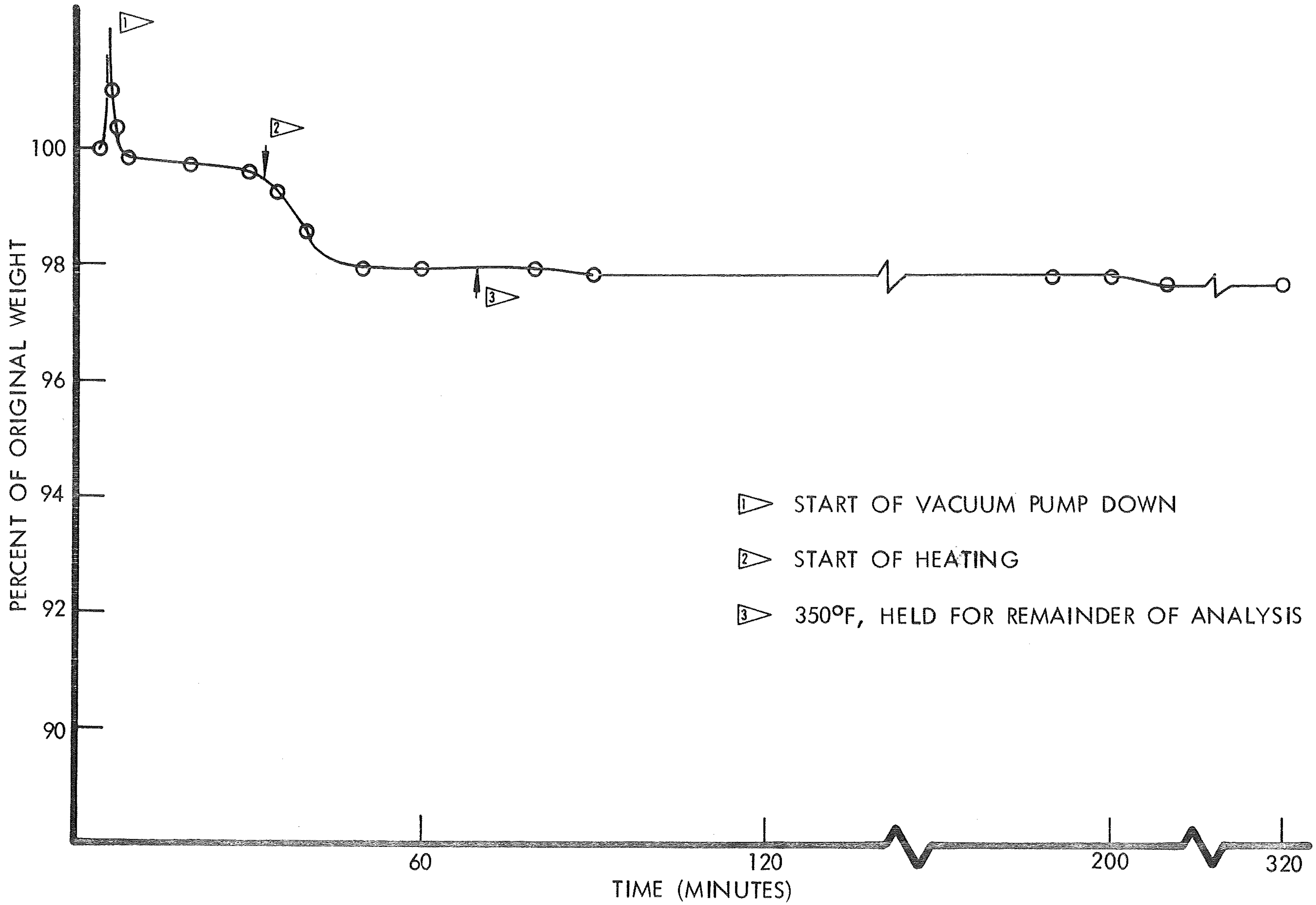


Figure 35 : ISOTHERMAL GRAVIMETRIC ANALYSIS (350°F IN VACUUM) METLBOND 329

D. Sandwich Assembly Outgassing Tests

The outgassing tests on five sandwich assemblies -1 through -5 (SK11-043157) were conducted on the vacuum outgassing apparatus shown in Figure 36. Tables 6 through 10 show the results of these tests. This limited test data does not recommend exposing the plastic portion of any of these assemblies to the evacuated MLI cavity. Further study might find solutions to the excessive outgassing. Adequate preconditioning to substantially reduce the outgassing might be accomplished through extended heating at 350°F. Selection of more thermally stable adhesives (presently in the development stage) would probably show considerable improvement in outgassing. However, it appears that achieving and maintaining an acceptable vacuum with organics exposed to the annulus will be difficult at best. Therefore, it is recommended that the metal inner shell approach be adopted.

2.2 45-Inch Diameter Hemispherical Shells

A. Design and Analysis

A.1 First Shell

Figures 37 and 38 show the first 45-inch diameter sandwich shell assembly.

Preliminary analyses were conducted to select materials for this shell. The analyses used the computer program previously described in the sandwich shell trades and were run using properties for 5056 aluminum flex-core. Temperature across shell was considered a constant 350°F. Probabilities of failure of 0.99, 0.90 and 0.50 were investigated. Configurations studied were:

(a) 6061-T6 - boron/epoxy
(b) 2219-T81 - boron/epoxy
(c) 6061-T6 - glass/polyimide
(d) 2219-T81 - glass/polyimide
(e) 6061-T6 - Glass/epoxy
(f) 2219-T81 - glass/epoxy

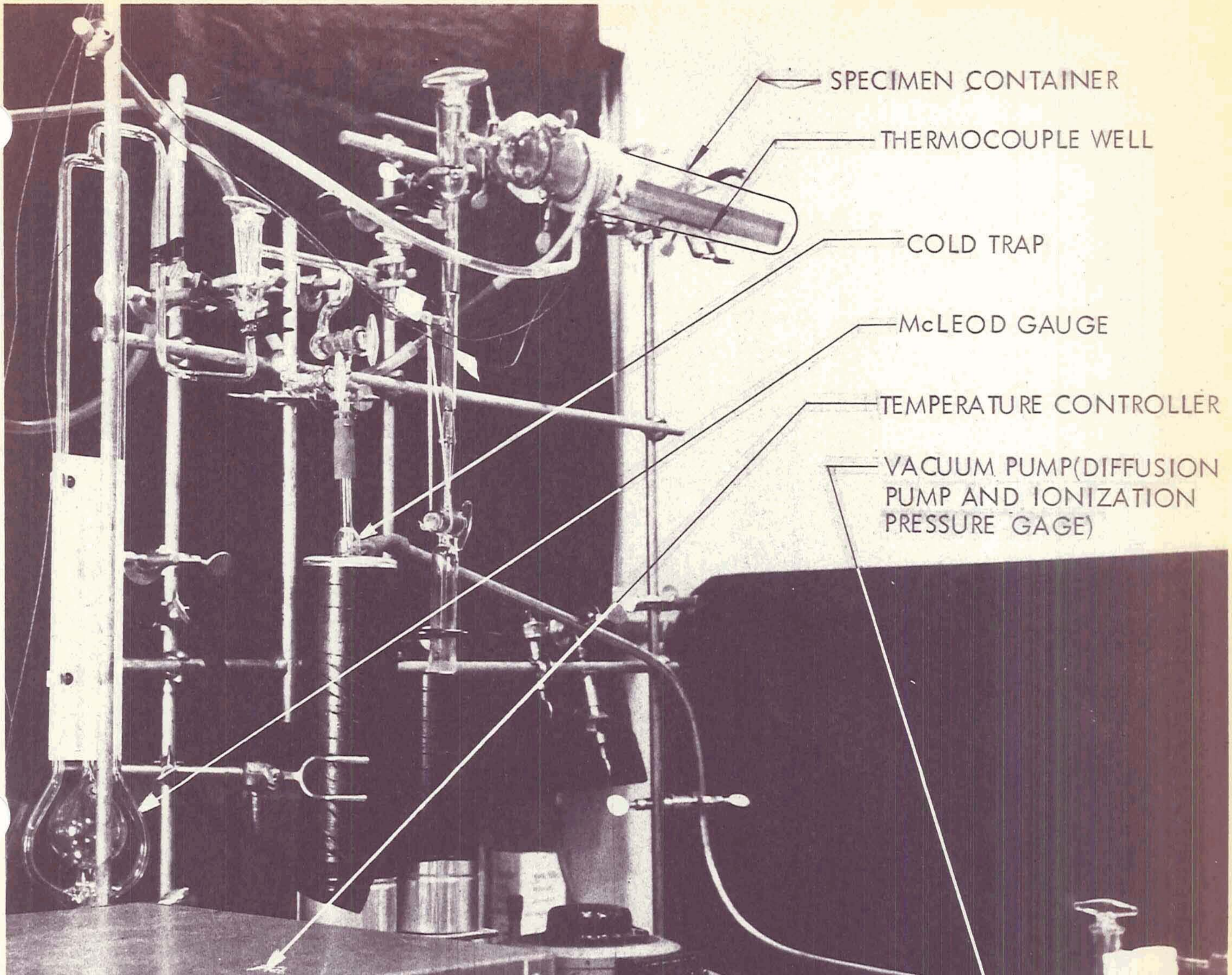


Figure 36: VACUUM OUTGASSING APPARATUS - MATERIAL OUTGASSING TEST

Table 6: RESULTS OF -1 ASSEMBLY VACUUM OUTGASSING TESTS AT 350°F [5]

Event No.	Duration of Exposure (hr) at 350°F	Cumulative Duration of Continuous Exposure (hr.) at 350°F	Pressure (torr)	Comments
1	Initial Value	-	6.5×10^{-3} [1]	[2]
2	.75	.75	6.5×10^{-3}	[2] [3]
3	1.75	1.75	7.5×10^{-3}	[2]
4	2.75	2.75	6.0×10^{-3}	[2]
5	3.75	3.75	2.0×10^{-3}	[2]
6	-	-	5.0×10^{-5}	[4]

[1] The lowest pressure achieved during an initial 4 hours vacuum pumping at room temperature was 1.3×10^{-3} torr. During heat up to 350°F the pressure increased to 6.5×10^{-3} torr due to specimen outgassing.

[2] These values are dynamic pressure values. The specimen-to-pump valve was maintained in the open position.

[3] Heat, and specimen-to-pump valve were shut off overnight. During this period the specimen experienced only cryogenic pumping at -110°F.

[4] After cooling to room temperature a pressure of 5×10^{-5} torr was achieved. With specimen-to-pump valve closed, this vacuum decayed to 2×10^{-4} torr (at room temp) after a 45 minute period of time.

[5] 2219 Aluminum container, fiberglass/phenolic (HRP) honeycomb core per BMS 8-124E, fiberglass/epoxy prepreg per BMS 8-139, and epoxy adhesive per BMS 5-17.

Table 7: RESULTS OF -2 ASSEMBLY VACUUM OUTGASSING TEST AT 350°F [6]

Event No.	Duration of Exposure (hr) at 350°F	Cumulative Duration of Continuous Exposure (hr.) at 350°F	Pressure (torr)	Comments
1	Initial Value	-	6.5×10^{-2} [1]	[2]
2	.75	.75	1.2×10^{-2}	[2]
3	2.00	2.00	8.0×10^{-3}	[2]
4	4.00	4.00	2.8×10^{-3}	[2]
5	[3]	[3]	[3]	[3]
6	Initial Value	4.00	2.8×10^{-3}	[4]
7	2.00	6.00	[5]	[4]

[1] The lowest pressure achieved after 1 hour vacuum pumping at room temperature was 1.5×10^{-4} torr. During heat up to 350°F (1/2 hour) the pressure increased to 6.5×10^{-2} due to specimen outgassing.

[2] These values are dynamic pressure values. The specimen-to-pump valve was maintained in the "open" position.

[3] The specimen-to-pump valve was closed at this point to obtain "static" pressures and vacuum decay rate at 350°F.

[4] The specimen-to-pump valve was kept closed for the remainder of the 350°F outgassing test.

[5] The pressure exerted due to specimen outgassing rose beyond the limit of the McLeod gauge scale which reads to a maximum of 1 torr.

[6] 2219 aluminum container, fiberglass/phenolic (HRP) honeycomb core per BMS 8-124E, fiberglass/polyimide prepreg per BMS 8-144 and epoxy adhesive per BMS 5-17.

Table 8: RESULTS OF -3 ASSEMBLY VACUUM OUTGASSING TEST AT 350°F [6]

Event No.	Duration of Exposure (hr) at 350°F	Cumulative Duration of Continuous Exposure (hr.) at 350°F	Pressure (torr)	Comments
1	Initial Value	-	9.0×10^{-3} [1]	[2]
2	1.25	1.25	8.2×10^{-3}	[2]
3	2.50	2.50	7.8×10^{-3}	[2]
4	[3]	[3]	[3]	[3]
5	Initial Value	2.50	7.8×10^{-3}	[4]
6	1.50	4.00	8.0×10^{-3}	[4]
7	3.50	6.00	[5]	[4]

[1] The lowest pressure achieved after 1 hour vacuum pumping at room temperature was 3.5×10^{-3} torr. During heat up to 350°F (1/2 hour) the pressure increased to 9.0×10^{-3} due to specimen outgassing.

[2] These values are dynamic pressure values. The specimen-to-pump valve was maintained in the "open" position.

[3] The specimen-to-pump valve was closed at this point to obtain "static" pressures and vacuum decay rate at 350°F.

[4] The specimen-to-pump valve was kept closed for the remainder of the 350°F outgassing test.

[5] The pressure exerted due to specimen outgassing rose beyond the limit of the McLeod gauge scale which reads to a maximum of 1 torr.

[6] 2219 aluminum container, fiberglass/phenolic (HRP) honeycomb core per BMS 8-124E, fiberglass/phenolic prepreg per BMS 8-129A and epoxy adhesive per BMS 5-17.

Table 9: RESULTS OF -4 ASSEMBLY VACUUM OUTGASSING TEST AT 350°F

[6]

Event No.	Duration of Exposure (hr) at 350°F	Cumulative Duration of Continuous Exposure (Hr.) at 350°F	Pressure (torr)	Comments
1	Initial Value	-	5.5×10^{-3} [1]	[2]
2	1	1	5.0×10^{-3}	[2]
3	2	2	3.8×10^{-3}	[2]
4	3	3	1.5×10^{-3}	[2]
5	[3]	[3]	[3]	[3]
6	Initial Value	3	1.5×10^{-3}	[4]
7	1	4	[5]	[4]
8	2	5	[5]	[4]

[1] The lowest pressure achieved after 1 hour vacuum pumping at room temperature was 2.2×10^{-3} torr. During heat up to 350°F (1/2 hour) the pressure increased to 5.5×10^{-3} due to specimen outgassing.

[2] These values are dynamic pressure values. The specimen-to-pump valve was maintained in the "open" position.

[3] The specimen-to-pump valve was closed at this point to obtain "static" pressures and vacuum decay rate at 350°F.

[4] The specimen-to-pump valve was kept closed for the remainder of the 350°F outgassing test.

[5] The pressure exerted due to specimen outgassing rose beyond the limit of the McLeod gauge scale which reads to a maximum of 1 torr.

[6] Titanium container, fiberglass/polyimide (HRH 327E) honeycomb core per BMS 8-125, fiberglass/polyimide prepreg per BMS 8-144 and metlbond 329 adhesive.

Table 10: RESULTS OF -5 ASSEMBLY VACUUM OUTGASSING TEST AT 350°F [6]

Event No.	Duration of Exposure (hr) at 350°F	Cumulative Duration of Continuous Exposure (hr.) at 350°F	Pressure (torr)	Comments
1	Initial Value	-	5.2×10^{-3} [1]	[2]
2	.83	.83	2.6×10^{-3}	[2]
3	1.83	1.83	2.0×10^{-3}	[2]
4	2.83	2.83	2.0×10^{-3}	[2]
5	[3]	[3]	[3]	[3]
6	Initial Value	2.83	2.0×10^{-3}	[4]
7	1.0	3.83	[5]	[4]
8	1.83	4.66	[5]	[4]

[1] The lowest pressure achieved after 1 hour vacuum pumping at room temperature was 5×10^{-4} torr. During heat up to 350°F (1/2 hour) the pressure increased to 5.2×10^{-3} due to specimen outgassing.

[2] These values are dynamic pressure values. The specimen-to-pump valve was maintained in the "open" position.

[3] The specimen-to-pump valve was closed at this point to obtain "static" pressures and vacuum decay rate at 350°F.

[4] The specimen-to-pump valve was kept closed for the remainder of the 350°F outgassing test.

[5] The pressure exerted due to specimen outgassing rose beyond the limit of the McLeod gauge scale which reads to a maximum of 1 torr.

[6] 2219 aluminum container, 5052 aluminum flex-core, boron/epoxy prepreg (Narmco 5505/14) and epoxy adhesive per BMS 5-17.

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED
	A	ADDED SHEET 3; NEW RELEASE -7 ASSEMBLY & COMPONENTS. ADDED FLAG NOTES 23,24,25,26, TO SHEET 1. ADDED -18 TO L/M & PICTURE	9-6-71	

26> UNIDIRECTIONAL SCOTCHPLY TAPE, TYPE 1400 (PHENOLIC GLASS LAMINATE) 3M C. REINFORCED PLASTICS DIV.

25> 6061-T4 OR T6 ALUM. PER QQ-A-250/11. (SIZE OPTIONAL FOR FABRICATION)

24> 2024-T3 ALUM SHEET, .010 × 36.0 × 72.0 PER QQ-A-250/4.

23> BOND METAL LAMINATES WITH PA 4459 (3M Co.)

22> CLEAN AND BOND PER BAC 5529. ADHESIVE BMS 8-145, TYPE I (AF-131, MINNESOTA MINNING AND MFG CO.) APPLIED TO FAYING SURFACES NOTED.

21> HELIUM LEAK CHECK WELD JOINT AT 1×10^{-5} TORR.

20> PENETRANT INSPECT WELDMENT PER BAC 5423.

19> HEAT TREAT TO T6 CONDITION PER BAC 5602

18> A CARD CERTIFYING THAT THE SANDWICH HEAD HAS BEEN ASSEMBLED PER CONDITIONS DESCRIBED ON THIS DRAWING AND SIGNED BY THE RESPONSIBLE MANUFACTURING ENGINEER, SHALL BE DELIVERED TO THE TECHNICAL LEADER ALONG WITH WEIGHT RECORDS 14>, SKIN THICKNESS RECORD 11> AND CONTOUR DIMENSION RECORD 12>.

17> THE ASSEMBLY SHALL BE PACKAGED AND SEALED IN A CLEAN POLYETHYLENE BAG PER BAC 5216, PARA 4.1 K(1) PRIOR TO STORING OR DELIVERY FOR TEST. SHIPPING METHOD TO TEST AREA WILL BE DETERMINED LATER.

16> ALL RAW MATERIALS, SUB ASSYS, & ASSYS SHALL BE PROTECTED FROM OIL & PARTICLE CONTAMINATION. ASSEMBLY SHALL BE DONE IN A DUST FREE ROOM.

15> RUBBER STAMP PART NUMBER AS SHOWN.

14> DETERMINE & RECORD WEIGHT OF DETAILS -2,-3,-4,-5,-18 & -1 ASSY; -8,-9,-10,-11,-12,-14,-15,-16,-17, & -7 ASSY

13> STRUCTURAL FOAMING ADHESIVE PER BAC 5-90, TYPE 2, CLASS 350, GRADE 50.

12> SHELL ASSY CONTOUR DIMENSIONS TO BE DETERMINED & RECORDED.

11> FINAL SKIN THICKNESS TO BE DETERMINED & RECORDED. ETCH NECESSARY INDEX MARKS ON INNER SURFACE OF -3 SKIN WHERE SHOWN.

10> FUSION WELD PER BAC 5935, CLASS A. EXCEPT RADIOGRAPHIC INSPECTION IS WAIVED. INSPECT WELD PER 20> 21>

9> 6061-T4 OR T6 AL PLATE 1.25 × 48.00 × 48.00, PER QQ-A-250/11.

8> CLEAN & BOND PER BAC 5540 EXCEPT ADHESIVE BMS 5-17, TYPE I, GRADE 2 (HT 424 BLOOMINGDALE DEPT, AMERICAN CYANIMID) SHALL BE APPLIED TO FAYING SURFACES NOTED.

7> DENSIFY CORE WITH 13> COMPLETELY AROUND PERIMETER TO LENGTH SHOWN, PER BAC 5514-590.

6> GLASS EPOXY PREPREG, PER BMS 8-139, TYPE 120, 1 PLY.

5> GLASS EPOXY PREPREG, PER BMS 8-139, TYPE 120, 2 PLY. GORE PATTERN TO BE DETERMINED. OVERLAP AT SEAMS, .10 TO .25 INCHES.

4> FLEXCORE 5056/F40-.0014 2.1 LB/FT³ ALUMINUM HONEYCOMB - PERFORATED, HEXCELL PRODUCTS INC. GORE PATTERN TO BE DETERMINED. SPLICE CORE GORES WITH 13>

3> CLEAN PER BAC 5514

2> 6061-O AL SHEET, .375 × 80.00 × 80.00, PER QQ-A-250/11.

1> DEVIATION FROM RADIUS ±.02, PROVIDED THE DISCONTINUITIES DO NOT EXCEED .02 IN 10.00 LENGTH IN ANY DIRECTION ALONG THE SURFACE.

LIST OF MATERIAL

-7	-1	QTY REQD	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	HT TR	FINISH	PT MK	REV LTR
✓		1	-18	REINFORCEMENT	B5-2	26> 14>				
✓		1	-17	RING	A5-3	25> 3> 14>	19>			A
✓		1	-16	POLAR CAP -10.0"	C1-3	24> 3> 14>				A
✓		1	-15	POLAR CAP -12.0"	C1-3	24> 3> 14>				A
✓		5	-14	DOUBLER	C1-3	24> 3> 14>				A
–		1	-13	BASE PLATE	A4-3	9>				A
✓		1	-12	REINFORCEMENT	A4-3	26> 14>				A
✓		1	-11	CORE	A4-3	4> 14>				A
✓		1	-10	FACE SKIN OUTER	A4-3	5> 14>				A
✓		10	-9	FACE SKIN GORE INNER	A4-3	24> 3> 14>				A
✓		1	-8	DOUBLER	A4-3	6> 14>				A
–	–	–	-7	HEMISPHERICAL SANDWICH HEAD ASSEMBLY	B2-3	14>			15>	A
	–	1	-6	BASE PLATE	B7-2	9>				
	✓	1	-5	CORE	B5-2	4> 14>				
	✓	1	-4	FACE SKIN OUTER	B5-2	5> 14>				
	✓	1	-3	FACE SKIN INNER	B5-2	2> 3> 14>	19>			
	✓	1	-2	DOUBLER	B6-2	6> 14>				
	–	–	-1	HEMISPHERICAL SANDWICH HEAD ASSY	C3-2	8> 14>		NONE	15>	

RELEASE

NEXT ASSY	USED ON	SECT NO	SERIAL NUMBER	PART NUMBER	RELEASE COLUMN NO	DWG SHT NUMBER	REV LTR
	(TEST ONLY)			-7			A
	(TEST ONLY)			-1			

APPLICATION

BASIC | RIVET | CODE

PART MARKING PER BAC 5307. RIVET INST & SYMBOLS PER BAC 5004. SEE BACD 2097 FOR SURFACE ROUGHNESS. FORM, PUNCH, STRAIGHTEN & FIT. METAL PARTS PER BAC 5300. BOLT & NUT INSTALLATION PER BAC 5009. MATERIAL SUBSTITUTION & EQUIVALENTS PER BAC 5025. FOR FINISH CODE SEE DOC D3-5000.

DWG ORIG BY (GROUP) 2-5085 CHANGE NO.

VENDOR ITEM-SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING

DIMENSIONING & TOLERANCING PER MIL-STD-8. UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: ANGLES ± 1°, DECIMALS ± .01. RIVET & BOLT EDGE MARGINS ± .03. BEND RADII: .01 ON .03 & .06; .03 ON .09 & GREATER. SHEET METAL CORNER RADII.

CONTR NAS 3-14369
DR C.W. OSBORNE 8-3-71
CHK
STRUCT
[signature] 8-27-71

THE BOEING COMPANY
AERO-SPACE DIVISION SEATTLE, WASHINGTON

HEMISPHERICAL SANDWICH HEAD - 45" DIA. LIGHTWEIGHT EVACUATED MLI (TEST ONLY)

SIZE E | CODE IDENT NO 81205 | SK11-043161
SCALE NONE | SH 1 OF 3

SK-11-043161- SHT 1 of 3 REV-A-

+2" HEAD

74

Figure 37

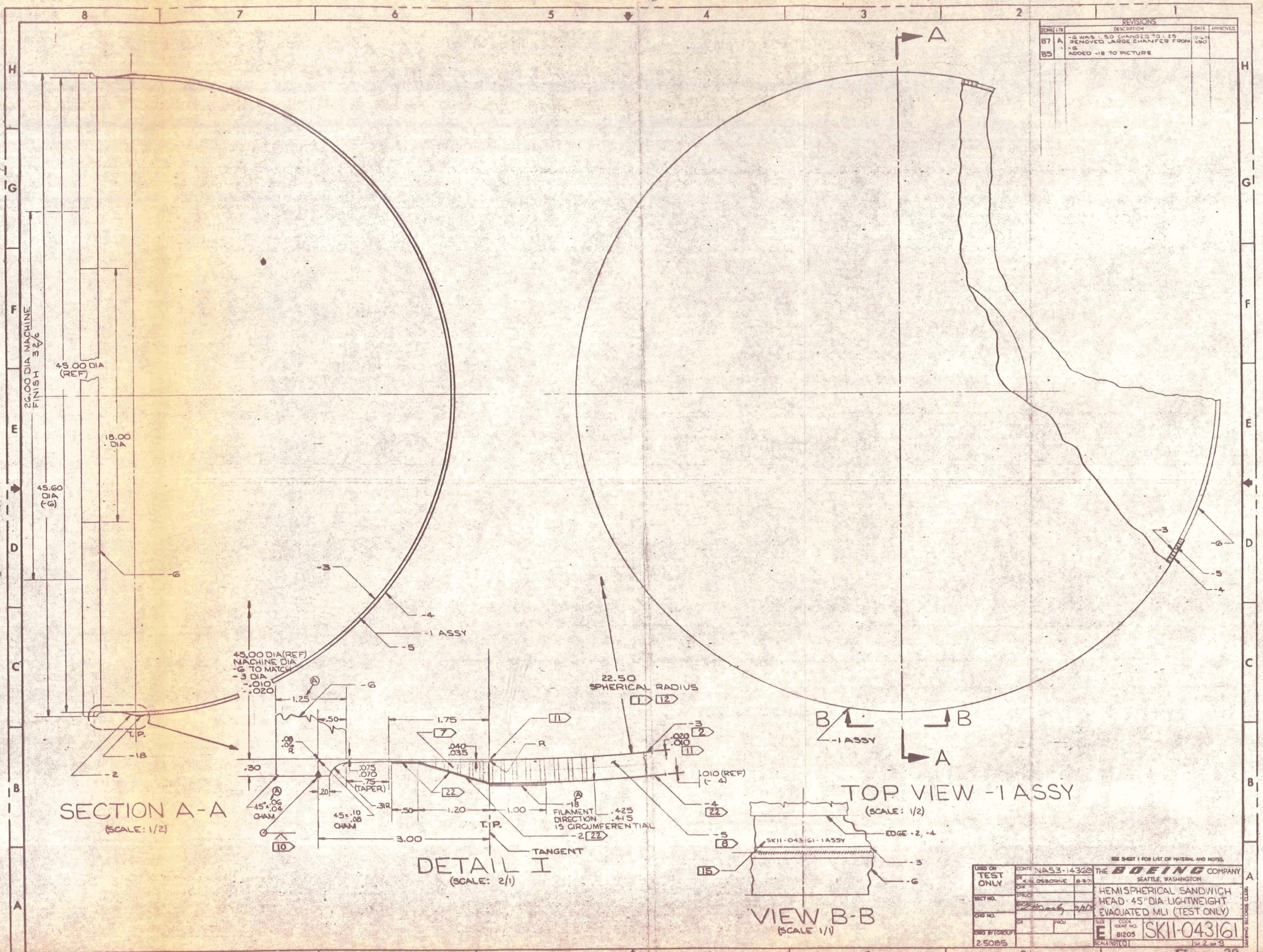


Figure 38.

SK11-043161 - SHT 2 of 3 REV-A

In each case, the face skins optimized at minimum gage (.010 inches). 6061-T6 was selected for Face 1, the metallic skin, in preference to 2219-T81 because of its apparent better adhesive bonding qualities. The 45-inch diameter shell tests are to provide data for the vacuum acquisition and shell analysis studies. Minimum shell weight was not considered of paramount importance for these shells. So, since glass/epoxy prepreg has better fabrication qualities than either glass/polyimide or boron/epoxy, it was selected for Face 2.

Using the materials selected, another analysis was conducted to determine flex-core thickness. The design pressure was 14.7 psi, the temperature 350°F and the probability of failing 0.01. Core thickness was determined to be 0.415 inches. Using this sandwich configuration the critical external pressure was then determined for a 0.50 and 0.99 probability of failing. The results from these analyses are summarized below:

Critical External Pressure (psi)	Probability of Failing	Failure Mode & Comments
14.7	.01	General Instability - Face 2 is critical at a stress of 3600 psi, S_1 = 9000 psi. Assumed T = 350°F
48.5	.50	General Instability - Face 2 is critical at a stress of 11,600 psi. S_1 = 29,000 psi (Used 350°F Moduli)
70.7	.99	Material Yielding - Face 1 is critical at a stress of 42,300* psi. S_2 = 16,900 psi. (Used 350°F Moduli)

* Estimated R.T., Average Strength

It is concluded from this analysis that failure can be expected within an acceptable pressure range, and that the desired general instability failure will occur prior to the non-representative material yielding.

The shell to base plate arrangement shown in Figure 38 provides the optimum practical vacuum acquisition configuration - an inner vacuum skin with a single girth weld joint which is accessible for leak checking and repair. Vacuum acquisition results from testing this shell at room temperature and +350°F will provide a baseline reference point from which to assess the vacuum acquisition characteristics of other vacuum skin fabrication methods in welded or bonded gore sections.

A.2 Second Shell

Figures 37 and 39 show the second 45-inch diameter sandwich shell assembly. The 5056 aluminum flex-core, 0.415 inches thick, and the 0.010 thick glass/epoxy prepreg outer face skins are also used on this shell. The inner face skin, however, is a laminate of two adhesive bonded foils. The foil is 2024-T3 aluminum, 0.010 thick. The adhesive selected is PA 4459 (3M Co.).

Testing of this shell will determine the magnitude of vacuum acquisition problems associated with the bonded laminate vacuum skin. Results can readily be compared with the first shell test results and from this, the reliability of the bonded laminate approach can be established.

B. Fabrication

All materials for both shells are on order. The spin block for the first shell is complete. The preform blank is in heat treat. Spinning will commence shortly. The high temperature fiberglass mandrel for the second shell is in work. This mandrel will be used for stretch forming the 2024-T3 aluminum and for layup of the hemisphere. The edge ring for the second shell is being machined.

C. Test

The test plan is in work, and test set-up design has commenced.

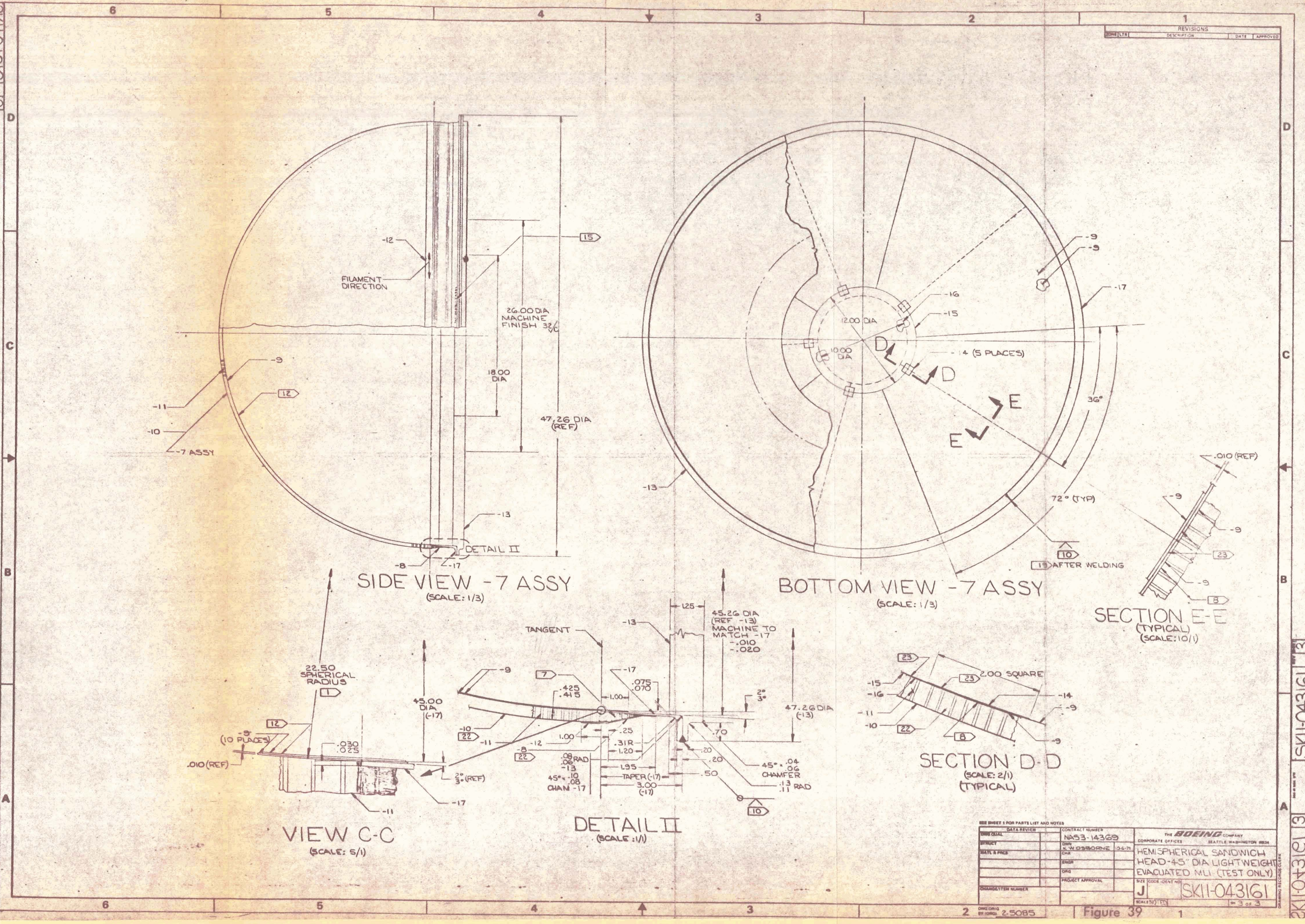

SIDE VIEW -7 ASSY
(SCALE: 1/3)
FILAMENT DIRECTION
26.00 DIA MACHINE FINISH 32/
18.00 DIA
47.26 DIA (REF)
DETAIL II
-7 ASSY
BOTTOM VIEW -7 ASSY
(SCALE: 1/3)
12.00 DIA
10.00 DIA
-14 (5 PLACES)
36°
72° (TYP)
AFTER WELDING
SECTION E-E
(TYPICAL)
(SCALE: 10/1)
.010 (REF)
SECTION D-D
(SCALE: 2/1)
(TYPICAL)
2.00 SQUARE
VIEW C-C
(SCALE: 5/1)
22.50 SPHERICAL RADIUS
(10 PLACES)
.010 (REF)
.030 .025
45.00 DIA (-17)
2° 3° (REF)
DETAIL II
(SCALE: 1/1)
TANGENT
45.26 DIA (REF -13) MACHINE TO MATCH -17 -.010 -.020
47.26 DIA (-13)
45° x .04 .06 CHAMFER
.13 .11 RAD
TAPER (-17)
45° x .10 .08 CHAN -17
THE BOEING COMPANY
CORPORATE OFFICES SEATTLE WASHINGTON 98124
CONTRACT NUMBER NAS3-14369
K WOSBORNE
HEMISPHERICAL SANDWICH HEAD-45" DIA LIGHTWEIGHT EVACUATED MLI (TEST ONLY)
J
SK11-043161
SHEET 3 of 3
2-5085

Figure 39

2.3 Non-Destructive Shell Buckling Test

A. 8-Foot Diameter Ellipsoidal Sandwich Shell Design and Analysis

Figures 40 and 41 show the 8-foot diameter shandwich shell assembly. The inner skin of this assembly is an existing 2219-T62 pressure vessel shell. This skin has a nominal thickness of 0.043 inches. Locally, it is thickened to 0.096 inches at the apex where a pickup lug is located, and to 0.073 inches at the equator.

The objectives of this test are to determine the adequacy of the non-destructive test technique and to obtain data for refining the sandwich shell analysis technique used in the Design and Trade studies. The trade study analyses assumed a factor of safety of 1.4 and a probability factor of 0.99 for limit design pressure of 14.7 psi. The non-destructive proof test may show these factors to be conservative. Assuming this conservatism, the 8-foot diameter shell is designed for a factor of safety of 1.4 and a probability factor of 0.5. This shell is expected to be stronger than the 14.7 psi design condition, but closer in strength to the 20.6 psi ultimate pressure than the 45-inch diameter shells. This should result in a more optimum weight design for the 8-foot shell.

Reference 5 states that the theoretical and experimental results for thin oblate spheroidal shells are similar to those for a sphere of radius

$$R_{max} = B^2/A$$

where

B is the apex height and

A is the equatorial radius

For the 2219-T62 shell

$$R_{max} = (48)^2/36 = 64 \text{ inches}$$

Therefore, the design is handled as though the oblate spheroidal shell were a hemisphere with a 64 inch radius. Sullins, Smith and Spier (Reference 2)

NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
   - SURFACE ROUGHNESS SYMBOLS PER BACD 2007
   - WELDING AND BRAZING SYMBOLS PER BACD 2023
   - FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300
   - MATERIAL SUBSTITUTIONS & EQUIVALENTS PER BAC 5005
   - PART MARKING PER BAC 5307
   - BOLT & NUT INSTALLATION PER BAC 5009
   - FINISH CODES PER DOCUMENT D3-5000
   - RIVET INSTALLATION & SYMBOLS PER BAC 5004

REV STATUS	
SH	LTR

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

17. A CARD CERTIFYING THAT THE SANDWICH HEAD HAS BEEN ASSEMBLED PER CONDITIONS DESCRIBED ON THIS DRAWING AND SIGNED BY THE RESPONSIBLE MANUFACTURING ENGINEER, SHALL BE DELIVERED TO THE TECHNICAL LEADER ALONG WITH WEIGHT RECORDS 12, SKIN THICKNESS RECORD 9, AND CONTOUR DIMENSION RECORD 10.
16. BOND -4 TO -3 PER BAC 5529, ADHESIVE BMS 8-145, TYPE 1, (AF 131 3 M Co) APPLIED TO FAYING SURFACES NOTED.
15. UNIDIRECTIONAL SCOTCH PLY TAPE TYPE 1400 (PHENOLIC GLASS LAMINATE) 3 M Co. REINFORCED PLASTIC DIV.
14. ALL RAW MATERIALS, SUB ASSEMBLIES & ASSEMBLYS SHALL BE PROTECTED FROM OIL & PARTICLE CONTAMINATION. ASSEMBLY SHALL BE DONE IN A DUST FREE ROOM.
13. ELECTRIC PENCIL OR STEEL STAMP PART NO. ON -7 INSIDE EDGE.
12. DETERMINE & RECORD WEIGHT OF DETAILS -7, -6, -5, -4, -3, -2, & -1 ASSY.
11. STRUCTURAL FOAMING ADHESIVE PER BAC 5-90, TYPE 2, CLASS 350, GRADE 50.
10. SHELL ASSY CONTOUR TO BE DETERMINED & RECORDED.
9. DETERMINE SKIN THICKNESS & RECORD. ETCH NECESSARY INDEX MARKS ON INNER SURFACE OF -2 AS SHOWN.
8. 6061-T6 OR T4 PLATE, .750 × 48.0 × 48.0, PER QQ-A-250/11
7. CLEAN & BOND PER BAC 5450 CLASS A, EXCEPT ADHESIVE BMS 5-17 TYPE 1, GRADE B, (HT 424, BLOOMINGDALE DEPT AMERICAN CYANIMID) SHALL BE APPLIED TO FAYING SURFACES NOTED.
5. GLASS EPOXY PREPREG PER BMS 8-139, TYPE 120, 1 PLY
4. GLASS EPOXY PREPREG PER BMS 8-139, TYPE 120 2 PLY. GORE PATTERNS TO BE DETERMINED. OVERLAP SEAMS .10 TO .25 INCHES.
3. FLEXCORE 5056/F40-.0014, 2.1 LBS/FT^3 ALUMINUM HONEYCOMB, HEXCEL PRODUCTS INC. GORE PATTERN TO BE DETERMINED. USE 11 AT CORE SPLICE JOINTS.
2. CLEAN PER BAC 5514
1. EXISTING PART - FURNISHED BY ENGINEERING, REF. MATL 2219-T62 ALUM.

	QTY	CODE IDENT NO	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	HT TR	FINISH	PT MK	SER BASE NUMBER	REV LTR
✓	6	–	-7	RING SEGNENT		8					
✓	1	–	-6	REINFORCEMENT		15					
✓	1	–	-5	DOUBLER		5, 16					
✓	1	–	-4	SKIN		4, 16					
✓	1	–	-3	CORE		3					
✓	1	–	-2	ELLIPTICAL DOME		1, 2					
–	–	–	-1	96.00 DIA SANDWICH HEAD ASSEMBLY		17, 14	—	—	13	—	

-1

RELEASE

PARTS LIST

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG SH NUMBER	REV LTR
	(TEST ONLY)				

APPLICATION

FASTENER CODES

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES: ANGLES ± 1°
DECIMALS .XX ± .01
DECIMALS .XXX ± .010
RIVET & BOLT EDGE MARGIN ± .03
BEND RADII ± .01 ON .03 & .06
± .03 ON .09 & GREATER
SHEET METAL CORNER RADII INT .16 .19/.10 EXT .22 .25/.09

DATA REVIEW: DWG QUAL; STRUCT; MATL & PRCS

CHANGE/ITEM NUMBER

CONTRACT NUMBER NAS3-14369
DWN K.W. OSBORNE 10-4-71
CHK
ENGR [signature] 10-14-71
ORG
PROJECT APPROVAL

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON 98124

ELLIPTICAL SANDWICH HEAD - 8' DIA - LIGHTWEIGHT EVACUATED MLI (TEST ONLY)

SIZE J | CODE IDENT NO | SK11-043166
SCALE N/A | SH 1 OF 2

DWG ORIG BY (ORG) 2-5085

DRAWING RECORDS CLERK

SK11-043166

Figure 40

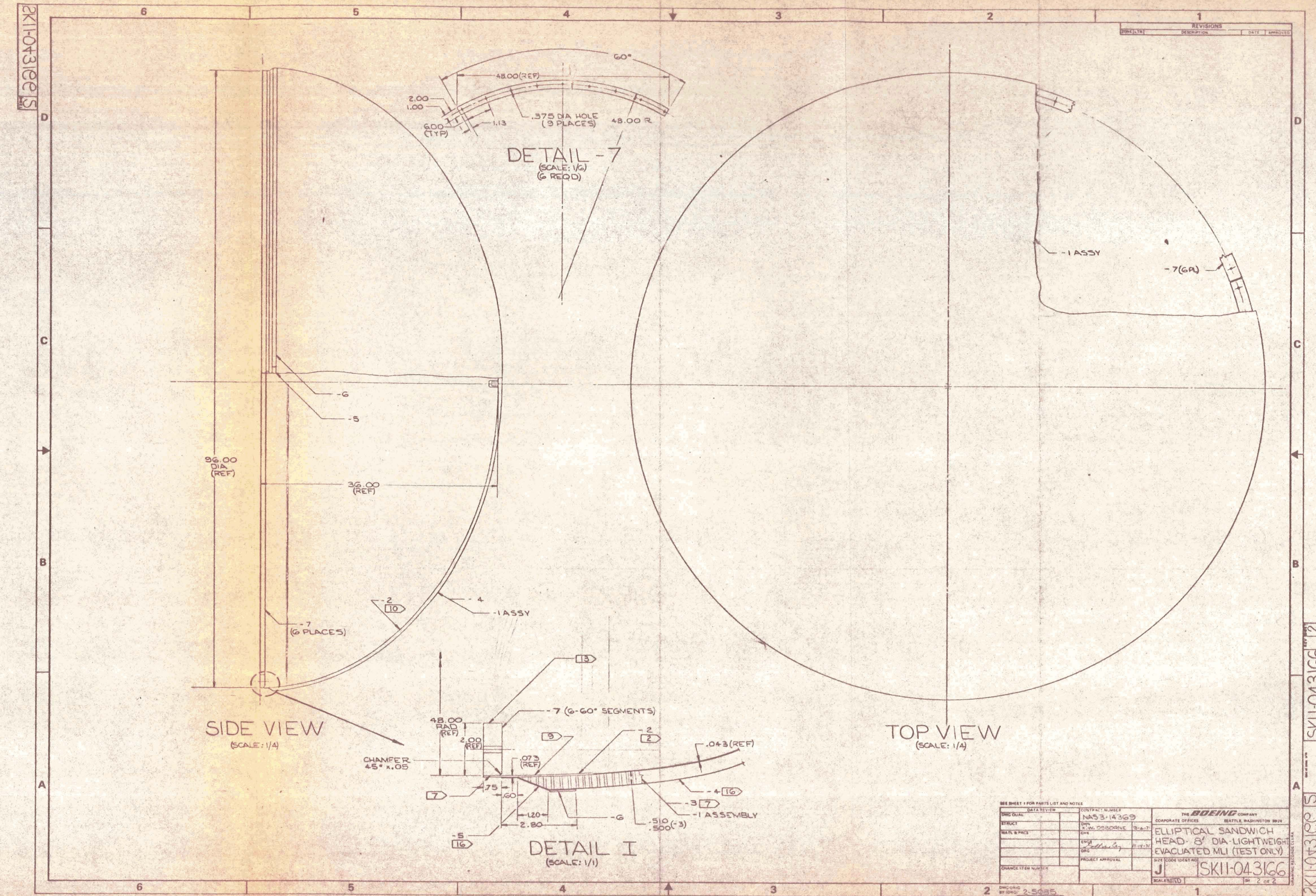

DETAIL - 7
(SCALE: 1/6)
(6 REQD)
60°
48.00 (REF)
2.00
1.00
6.00 (TYP)
1.13
.375 DIA HOLE (9 PLACES)
48.00 R
96.00 DIA (REF)
36.00 (REF)
-6
-5
-4
-1 ASSY
-2
10
-7 (6 PLACES)
SIDE VIEW
(SCALE: 1/4)
TOP VIEW
(SCALE: 1/4)
-1 ASSY
-7 (GR)
-7 (6-60° SEGMENTS)
13
48.00 RAD (REF)
2.00 (REF)
CHAMFER 45° x .05
.073 (REF)
9
-2
2
.043 (REF)
-4
16
-3
7
-1 ASSEMBLY
.510
.500 (-3)
.75
.60
1.20
2.80
-6
-5
16
7
DETAIL I
(SCALE: 1/1)
CONTRACT NUMBER NAS3-14369
THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON
ELLIPTICAL SANDWICH HEAD - 8' DIA - LIGHTWEIGHT EVACUATED MLI (TEST ONLY)
J
SK11-043166
SH 2 of 2
2-5085
SK11-043166 S
SK11-043166 2

Figure 41

treat the sandwich shell in the same manner. In addition, they have summarized test data to determine the knockdown factor for sandwich domes subjected to uniform external pressure. These data are summarized in Figure 42.

OPTRAN designs were made for this shell using probability factors of 0.5, 0.90 and 0.99. The results were:

<u>Optimum Vacuum Jacket Designs for 8-Ft. Diameter Shell</u>

Face 1 - .043, 2219-T62 Aluminum

Face 2 - Style 120 Fiberglass Epoxy Prepreg

Core - 5056 Aluminum Flex Core

(Design Pressure = 20.6 psi, R = 64 In.)

Probability of Not Failing	t_1 (in.)	t_2 (in.)	t_c (in.)	Core Density (PCF)
0.5	.043	.010	0.345	2.1
0.90	.043	.010	0.625	2.1
0.99	.043	.010	0.963	2.1

Using the recommended design factors from Reference 2, the core depth should be 0.58 inches. This would produce an R_{max}/ρ value of 64/.3 = 213. The data shown in Figure 42 are for an R_{max}/ρ = 250. A core thickness of 0.500 inches provides R_{max}/ρ = 64/0.500 = 250.

After considering the OPTRAN designs with the Boeing statistical analysis and the recommended design approach of Reference 2, with the test data shown in Figure 42, a core thickness of 0.500 inches was selected. Using the experimental data for the knockdown factors shown, the expected critical external pressures are:

<u>8-Ft. Diameter Shell - Expected Critical Pressures</u>

Face 1 - 2219-T62 Aluminum, .043 inch

Face 2 - Fiberglass/Epoxy (120 fabric), .010 inches

Core - Aluminum Flex-Core, .500 inches

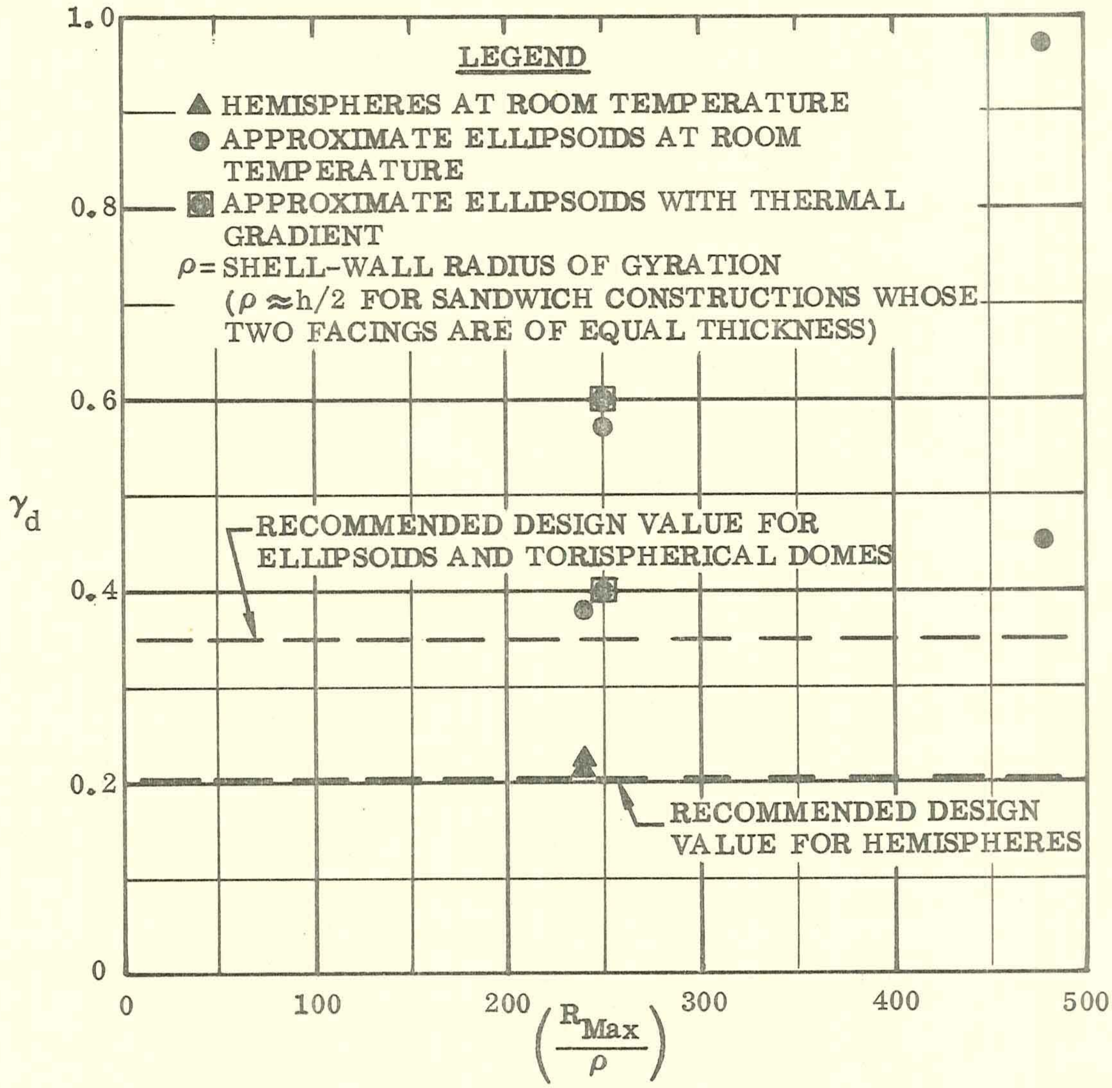


FIGURE 42: KNOCK-DOWN FACTOR γ_d FOR SANDWICH DOMES SUBJECTED TO UNIFORM EXTERNAL PRESSURE (REFERENCE 2)

Maximum external pressure	=	33 psi
Average external pressure	=	27 psi
Minimum external pressure	=	21 psi

Both of these analyses assume simply supported edge conditions. That is, during buckling there are no radial displacements and no edge moments on the shell. Designs of the actual vacuum jacket will have to provide suitable ring stiffening at the edges of the dome. In the test head ring stiffening will be provided internally by plate segments bolted to the base plate. There will be some edge moment on the shell provided by the bending stiffness of the .073 inch thick edge and the fiberglass reinforcement. This is less than half the sandwich bending stiffness and should not substantially increase the experimental critical pressure.

B. Fabrication

The material is on order.

C. Test

Work on the setup arrangement has commenced.

3.0 TASK III - Data Evaluation and Reports

No data evaluation was initiated.

CURRENT PROBLEMS

No technical or budgetary problems are foreseen.

PLANNED ACTIVITIES FOR NEXT REPORTING PERIOD

Design and trade studies, and evaluation will continue. Fabrication of the two 45-inch diameter shells will continue. Work on the test plan and setup for the 45-inch diameter shells will continue.

D. L. Barclay - Technical Leader

D. K. Zimmerman - Program Leader

REFERENCES

1. TSB 120, "Mechanical Properties of Hexcel Honeycomb Materials," Hexcel Aerospace, Revised 1971.

2. Sullins, R.T., et al; "Manual for Structural Stability Analysis of Sandwich Plates and Shells," N70-14135, December 1969.

3. Kuenzi, E.W., Bohannan, B., and Stevens, G.H.; "Buckling Coefficients for Sandwich Cylinders of Finite Length Under Uniform External Lateral Pressure," U.S. Forest Service Research Note FPL-0104, September 1965.

4. Yao, J.C.; "Buckling of Sandwich Sphere Under Normal Pressure," Journal of the Aerospace Services, March 1962.

5. NASA SP-8032, "Buckling of Thin-Walled Doubly Curved Shells", August 1969.

6. A. D. Little Report, "Advanced Studies on Multilayer Insulation Systems", NASA CR-54929, Contract NAS 3-6283, June 1966.

7. McDonnell-Douglas Astronautics Company, "Ranking and Selection of Insulation Systems for MNV Application", Special Report No. 1, Contract NAS 8-21400.

8. Boeing Document D2-121085-1, "Space Vehicle Integrated Thermal Protection/Structural Meteoroid Protection System", June 1969.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION	CONTRACT PROGRESS SCHEDULE	REPORT FOR MONTH ENDING September 30, 1971	FORM APPROVED. BUDGET BUREAU NO. 104-R0007	9. NASA Use Only a. NASA CODE
1. CONTRACT TITLE LIGHTWEIGHT EVACUATED MULTILAYER INSULATION SYSTEMS FOR THE SPACE SHUTTLE VEHICLE	2. CONTRACTOR (Name and address) The Boeing Company - ASG - Research and Engineering Division Kent Facility - P.O. Box 3999, Seattle, Washington 98124		3. CONTRACT NO. NAS3-14369	b. PROJECT MGR.
	4. APPROVED (Contractor's Project Manager) D. Zimmerman	PREPARATION DATE Oct. 1, 1971	5. NASA APPROVED SCHEDULE DATE April 12, 1971	c. EVALUATION DATE
				d. EXCEPTION CATEGORY

6. REPORTING CATEGORY	1971: A M J J A S O N D	1972: J F M A M J J A S O N D	1973: J F M	8. TECH. OBJECTIVE % COMP.	e.	f.	g.
TASK I - DESIGN CONCEPTS EVALUATION							
(1) Design & Trade Studies	2			85%			
(2) Final Evaluations & Recommendations				9%			
TASK II - VACUUM SHELL STRUCTURAL TESTS AND VACUUM ACQUISITION TESTS							
(1) Material Outgassing Tests	2			100%			
(2) 45" Dia. Sandwich Heads Fabrication				25%			
(3) Vacuum Acquisition and External Pressure Tests - 45" Dia Heads				2%			
(4) External Pressure Tests - 8' Dia. Head							
TASK III - DATA EVALUATION & REPORTS				18%			

NASA-C-63 (Rev. 1-68)

NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

Figure 43